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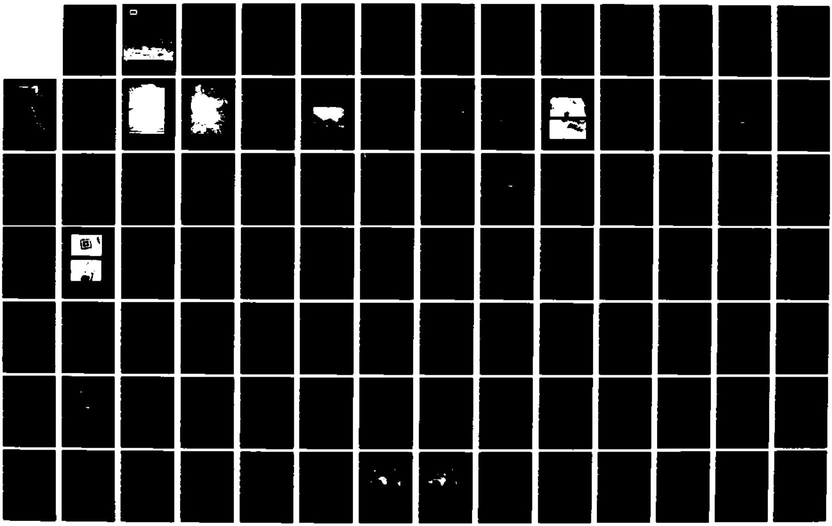

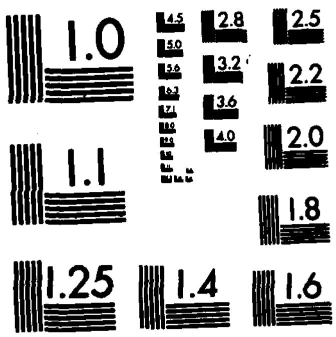
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TECHNICAL REPORT GL-83-1

CAVITY DETECTION AND DELINEATION RESEARCH

Report 1

MICROGRAVIMETRIC AND MAGNETIC SURVEYS: MEDFORD CAVE SITE, FLORIDA

by

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March 1983
Report 1 of a Series

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under CWIS Work Unit No. 31150

Technical Report GL-83-1

CAVITY DETECTION AND DELINEATION RESEARCH

	Title	Author
Report 1:	Microgravimetric and Magnetic Surveys: Medford Cave Site, Florida	Dwain K. Butler
Report 2:	Seismic Methodology: Medford Cave Site, Florida	Joseph R. Curro, Jr.
Report 3:	Acoustic Resonance and Self-Potential Applications: Medford Cave and Manatee Springs Sites, Florida	Stafford S. Cooper
Report 4:	Microgravimetric Survey: Manatee Springs Site, Florida	Dwain K. Butler, Charlie B. Whitten, Fred L. Smith
Report 5:	Electromagnetic (Radar) Techniques Applied to Cavity Detection	Robert F. Ballard, Jr.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report GL-83-1	2. GOVT ACCESSION NO. AD-A124	3. RECIPIENT'S CATALOG NUMBER 574
4. TITLE (and Subtitle) CAVITY DETECTION AND DELINEATION RESEARCH: Report 1, MICROGRAVIMETRIC AND MAGNETIC SURVEYS: MEDFORD CAVE SITE, FLORIDA		5. TYPE OF REPORT & PERIOD COVERED Report 1 of a series 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Dwain K. Butler		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Geotechnical Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS CWIS Work Unit No. 31150
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE March 1983 13. NUMBER OF PAGES 136
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Cavities (Underground) Geophysical exploration Gravimetric surveys Medford Cave Subsurface exploration		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report reviews the scope of a research effort initiated in 1974 at the U. S. Army Engineer Waterways Experiment Station with the objectives of (a) assessing the state of the art in geophysical cavity detection and delineation methodology and (b) developing new methods and improving or adapting old methods for application to cavity detection and delineation. Two field test sites were selected: (a) the Medford Cave site with a relatively shallow (10- to 50-ft-deep) air-filled cavity system and (b) the Manatee Springs site

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20. ABSTRACT (Continued).

with a deeper (approximately 100-ft-deep) water-filled cavity system. Results of field studies at the Medford Cave site are presented in this report: (a) the site geology, (b) the site topographic survey, (c) the site drilling program (boreholes for geophysical tests, for determination of a detailed geological cross section, and for verification of geophysical anomalies), (d) details of magnetic and microgravimetric surveys, and (e) correlation of geophysical results with known site geology.

Although some correlation was observed at the Medford Cave site between magnetic anomalies and other geophysical anomalies and with geological conditions revealed by drilling, the magnetic survey in general did not yield results which were of value in defining this site. The microgravimetric survey, however, was extremely successful. The known cavity system was delineated as to locations and trends of cavities by the gravity anomaly maps. Six selected negative gravity anomaly features, in areas of the site with previously unknown subsurface conditions, were drilled for verification purposes, and all borings intercepted air- or clay-filled cavities or clay- or sand-filled pockets in the top of the limestone. Of 11 borings in positive gravity anomaly areas, only three intercepted cavities. The cavity system was adequately detected and delineated using a 20-ft station spacing. A station spacing of 10 ft allowed detection of smaller scale cavities and other solution features in the top of the limestone.

Using simple assumed models for the cavities, computed depths to tops of cavities agree to better than 25 percent, thicknesses to better than 40 percent, and areal extent of cavities to better than 15 percent of known cavity dimensions. These percentages are completely model-dependent and in no way reflect the accuracy of the survey or the microgravimetric technique.

Qualitative interpretation guidelines using complementary geophysical techniques for site investigations in karst regions are presented. Including the results of electrical resistivity surveys conducted at the Medford Cave site, the qualitative guidelines are applied to four profile lines, and drilling locations are indicated on the profile plots of gravity, magnetic, and electrical resistivity data. Borehole logs are then presented for comparison with the predictions of the qualitative interpretation guidelines.

PREFACE

This investigation was performed by personnel of the Earthquake Engineering and Geophysics Division (EEGD), Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES), for the Office, Chief of Engineers (OCE), U. S. Army, during the period May 1979 to November 1980. The investigation was part of CWIS Work Unit No. 31150, "Remote Delineation of Cavities and Discontinuities."

This report was prepared by Mr. Dwain K. Butler, EEGD. The field work described in this report was performed by Messrs. Butler, Joseph R. Curro, Jr., and Rodney N. Walters, EEGD, and was closely coordinated with other studies at this site conducted under this same work unit, work carried out under an In-House Laboratory Independent Research (ILIR) Project, "Microgravimetric Techniques for Geotechnical Application," and the Project 4A161102AT22, Work Unit 002/Q6, "Analytical and Data Processing Techniques for Interpretation of Geophysical Properties."

Assistance with field programs at the Medford Cave site was provided by Messrs. J. D. Gammage, William Stelz, Bill Wisner, and Dr. Robert Ho of the Florida Department of Transportation, Gainesville, Fla. Assistance of personnel of Southwest Research Institute, San Antonio, Tex., in obtaining cavity and site maps, supplying information about their previous work at the site, and other assistance throughout this investigation is gratefully acknowledged. Mr. William D. Reves, Ocala, Fla., served as geological consultant for the work, assisted in core logging, and prepared Appendix A of this report.

Special acknowledgement is given to Professor Robert Neumann and the Compagnie Generale de Geophysique (CGG), Massy, France. Professor Neumann provided encouragement and assistance throughout the program. In July 1979, Mr. Butler visited Professor Neumann with data from the microgravity survey at the Medford site. Professor Neumann, Mr. Jacques Regnaudin, and other colleagues at CGG assisted in the data processing and preparation of anomaly maps and documented their contributions in a letter report under Contract Agreement DAJA 37-79-M-0027.

A Sharpe Magnetometer, Model MF1-100, was obtained on loan from

the Department of Geophysics, Texas A&M University, for use during this work. Also, a LaCoste and Romberg Gravimeter, Model D4, was loaned to WES by the U. S. Army Engineer District, Seattle.

The work was performed under the direct supervision of Dr. A. G. Franklin, Chief, EEGD, and the general supervision of Dr. W. F. Marcuson III, Chief, GL. Mr. Paul Fisher was the OCE Point of Contact for the CWIS work, and Mr. Curro was the WES Principal Investigator for the Work Unit.

Commanders and Directors of WES during the performance of this work and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Mr. Fred R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report may be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
feet	0.3048	metres
feet per mile	0.18939	metres per kilometre
inches	2.54	centimetres
miles (U. S. statute)	1.609347	kilometres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

CAVITY DETECTION AND DELINEATION RESEARCH

MICROGRAVIMETRIC AND MAGNETIC SURVEYS: MEDFORD CAVE SITE, FLORIDA

PART I: INTRODUCTION

Background

1. In 1974, a research program, funded by the Office, Chief of Engineers (OCE), U. S. Army, was initiated at the U. S. Army Engineer Waterways Experiment Station (WES) with the objectives of assessing the state of the art in geophysical cavity detection and delineation methodology and developing new methods and improving or adapting old methods for application to cavity detection and delineation. Briefly, the primary phases of the research effort are listed below:

- a. In 1976, a controlled test facility was constructed at WES, and a number of artificial (man-made) cavities were made available for testing and evaluating geophysical survey methods. Results of geophysical tests conducted at the facility and details of the facility itself are reported by Butler and Murphy (1980).
- b. The Symposium of Detection of Subsurface Cavities was held at WES in July 1977 (Butler 1977). The Symposium reviewed the state of the art and attempted to define the scope of the problems faced by Corps of Engineers Districts and Divisions at major construction projects in areas with subsurface cavities, primarily areas with solution susceptible bedrock.
- c. Early in 1979, two natural field sites in karstic regions, for which cave maps were available, were selected for testing and evaluating geophysical methods. The first site, Medford Cave, in Marion County, Fla., has a relatively shallow (approximately 10 to 50 ft or 3 to 15 m)*

* In many instances, metric units follow the English units parenthetically and dual axis units are included in graphs. By convention, the gamma (γ) is used as the unit of magnetic field strength, and the μGal is used as the unit of gravitational acceleration in microgravimetric surveying; these units are defined in the text. Also, the unit grams per cubic centimetre for density is used throughout the report. A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

air-filled cavity system. The second site, Manatee Springs, in Levy County, Fla., has a somewhat deeper (approximately 100 ft or 30 m) water-filled cavity system. In addition to the known and mapped cavity systems, both sites have additional cavities and other solution features common to karst regions.

2. This report documents results and presents conclusions derived from analyses of microgravity and magnetic survey data obtained at the Medford Cave site. In addition to the microgravimetric and magnetic surveys, numerous additional geophysical methods have been applied at the site, including the following:

a. Seismic methods.

(1) Standard surface seismic refraction.

(2) Surface shear wave refraction.

(3) Constant spacing refracted wave form (Curro, Cooper, and Ballard 1980).

(4) Surface seismic reflection.

(5) Crosshole seismic method (Ballard 1976 and Butler, Skogland, and Landers 1978).

(6) Uphole seismic refraction (Franklin 1980).

(7) Fan "shooting" (circular arc geometry).

b. Electrical resistivity.

(1) Horizontal profiling (Wenner array) to produce site resistivity countour map.

(2) Vertical sounding (Wenner array).

(3) Pole-dipole survey (Bristow-Bates method; Bates 1973 and Butler and Murphy 1980).

c. Acoustic reasonance (subsurface source) (Cooper and Bieganousky 1978, and Curro, Cooper, and Ballard 1980).

d. Electromagnetic methods (radar).

(1) Surface radar horizontal reflection profiling (approximately 100 MHz).

(2) Crosshole radar vertical profiling.

e. Borehole geophysical logging.

(1) Caliper.

(2) Natural gamma.

(3) Gamma-gamma.

(4) Neutron.

Results of these additional geophysical surveys will be presented in subsequent reports in this series.

Purpose

3. The purposes of this investigation were to (a) determine whether surface microgravity and magnetic surveys would indentify anomaly patterns consistent with known cavity geometry, (b) investigate the use of the methods to detect previously unknown cavity or other solution features at the site, and (c) determine size and depth detectability of solution features and ability of the methods to resolve closely spaced features.

4. While this report covers specifically the field procedures and results of the microgravimetric and magnetic surveys at the Medford site, reference to the results of other surveys at the site will be made, where appropriate, without detailed discussion of the field procedures or results of the other surveys, leaving detailed discussions to subsequent reports.

Scope

5. Part II of this report discusses the Medford Cave site, including area geology, site geology, the known cave system, and the site drilling program. Part III describes the magnetic survey and results, and Part IV describes the microgravimetric survey and results. Correlations of the microgravimetric and magnetic results with each other and with known geology and the results of the site drilling program are presented in Part V. Part VI contains the summary and conclusions.

PART II: THE MEDFORD CAVE SITE

Location

6. Medford Cave (or Medford's Cave) is located in Marion County, Fla., about 1 mile south of Reddick. The location of Medford Cave as well as the Manatee Springs test site is shown in Figure 1. A portion of the U. S. Geological Survey Reddick Quadrangle (1968) is shown in Figure 2, with the approximate site location indicated. Figure 3 is an aerial photograph of the Medford Cave site (circa 1974); the main entrance to the cave system is hidden in the cluster of trees in the center of the photograph.

History of Site Use

7. The Medford Cave is located on land formerly part of the Medford Plantation. Apparently, the cave system has been known at least since the time the plantation was in operation, and stories are told of people being lost in the cave and of people entering and then emerging at sinkholes 1 and 2 miles away. A steel ladder was installed in the primary entrance (Figure 4) reportedly in the 1940's, and the cave has been a popular excursion site for people in the vicinity and for speleological groups. The land around the site has been used for both vegetable farming and livestock grazing.

8. Scientific use of the site began in the early 1970's when the Southwest Research Institute (SwRI), San Antonio, Tex., with the assistance of the Florida Department of Transportation, Gainesville, selected the site for evaluation of three geophysical methods for cavity/tunnel detection (Fountain, Herzig, and Owen 1975). In addition to mapping the cavity system, the investigators conducted a standard gravity survey, a surface ground-penetrating "radar" survey (electromagnetic survey), and resistivity surveys. All of the methods were only moderately successful at the site, with the results of the pole-dipole resistivity surveys considered the most definitive. The radar method was apparently limited

Figure 1. Map showing locations of Medford Cave and Manatee Springs sites

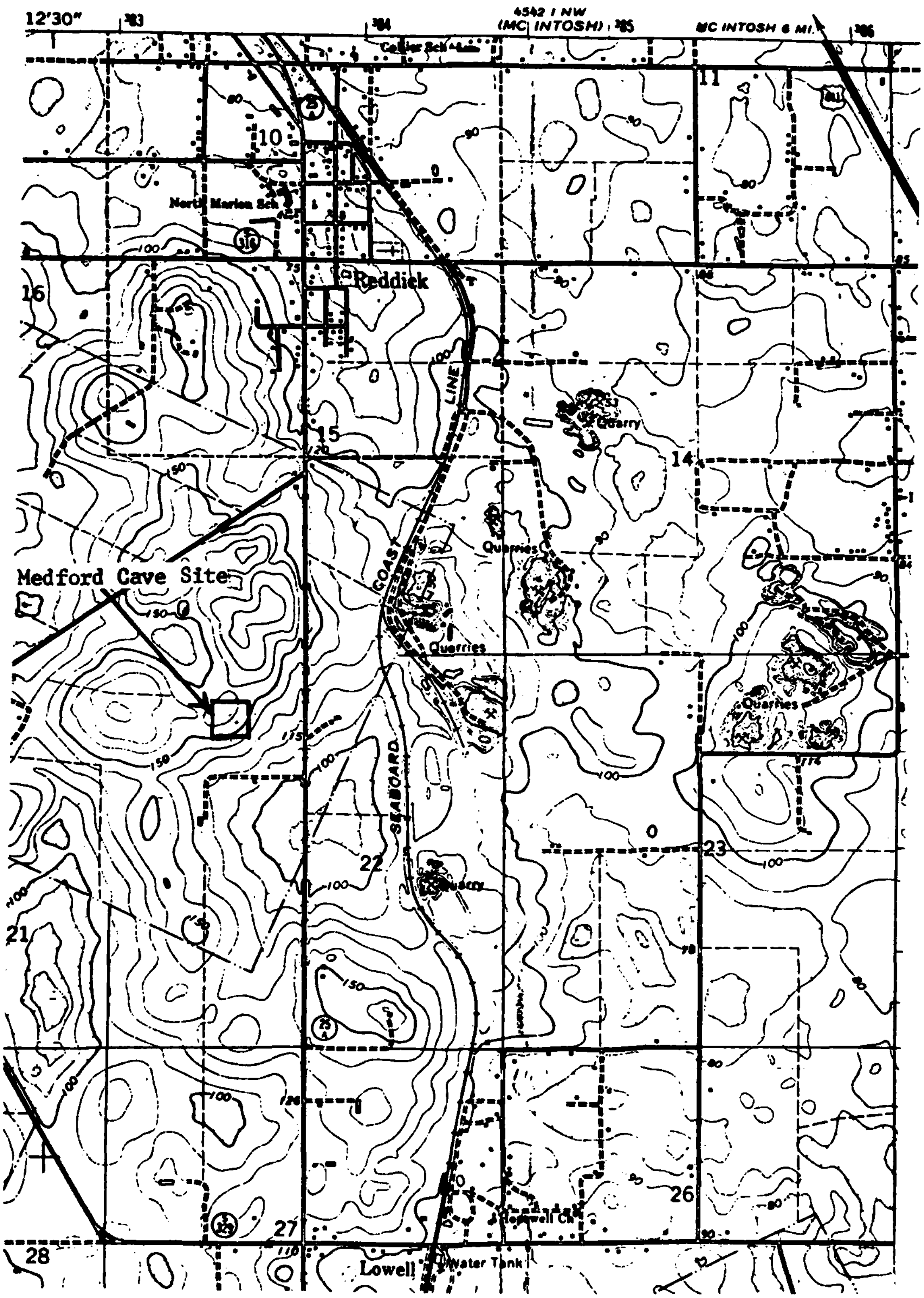

Figure 2. Portion of U. S. Geological Survey, Reddick, Fla., quadrangle sheet (1968) showing Medford Cave test site

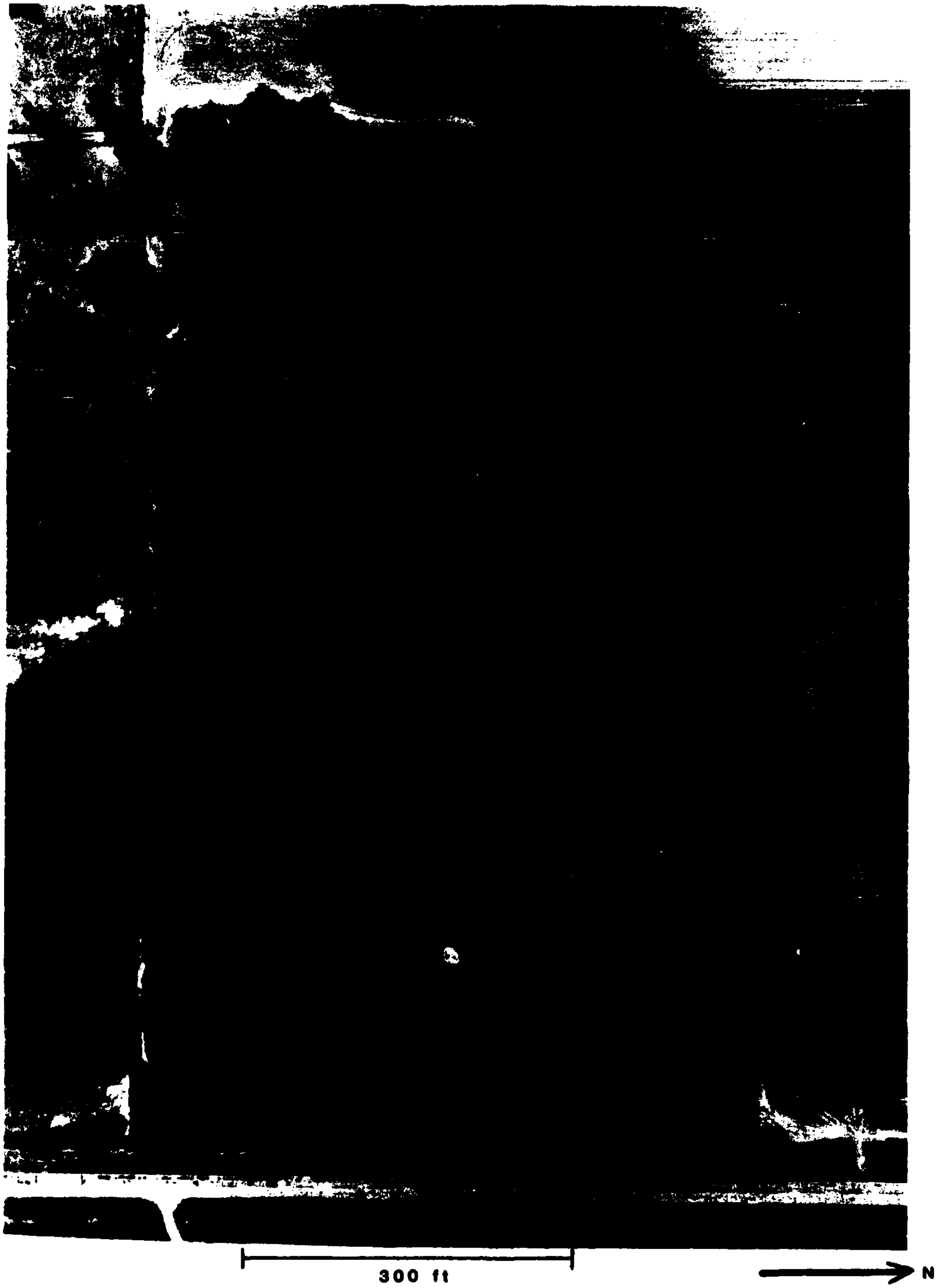

Figure 3. Aerial photograph of Medford Cave site

Figure 4. Entrance sink, Medford Cave site, Fla., showing steel ladder

to detection depths shallower than about 15 ft (4.5 m). The gravity survey results did not correlate very well with the known cavity system, indicating anomalies which were close but not directly over the largest of the cavity rooms. Only three verification borings were placed at the site, with each boring in an area where at least two of the methods indicated anomalies. However, all three borings encountered only solid material to depths of 32 to 52 ft (9.8 to 15.8 m).

9. WES personnel visited the site in early 1979 on a tour of several candidate sites for use in the cavity detection and delineation research program. Several factors contributed to the selection of the Medford Cave as the first of two test sites planned under the program:

- a. A cavity system almost entirely air-filled.
- b. Easy site access.
- c. Gently sloping topography.
- d. Wide range of cavity sizes.
- e. Known portion of cavity system shallow, but with a good range of cavity depths.
- f. Cavity system presumably well-mapped.
- g. Available results of previous geophysical tests at the site.

The Florida Department of Transportation agreed to obtain site use approval and to assist in the test program, which began in May 1979.

Geology

Area geology

10. The Medford Cave site is situated near the east-central flank of the Ocala Uplift, a northwest-southeast trending "anticlinal structure" (Faulkner 1970). Although the Ocala Uplift is apparently bounded by faults, the area is considered tectonically stable. The primary active geological process affecting the area is solutioning of limestones and dolomites to produce karst topography with little surface drainage, development of subsurface cavities, sinkhole formation, etc. Local relief in the area is about 110 ft (34 m) and consists of gently

rolling hills and valleys. Generally the hills are capped by only a few feet of sands and clays over limestone. The shallow depth to top of limestone has resulted in many limestone quarries in the area. Extensive cave systems with attendant sinkhole formation are commonly associated with the hills and higher limestone elevations. The general geology of the area and of the Medford Cave site in particular is covered in Appendix A.

Site geology

11. The general sequence of materials at the Medford Cave site is sand (with silt, clay, and organic material), clay (may or may not be present at a given location), and limestone. Typically, the sand ranges from nearly 0 to about 4 ft in thickness. The clay (residual) occurs primarly in pockets in the limestone surface. Figure 5 shows a cut at a

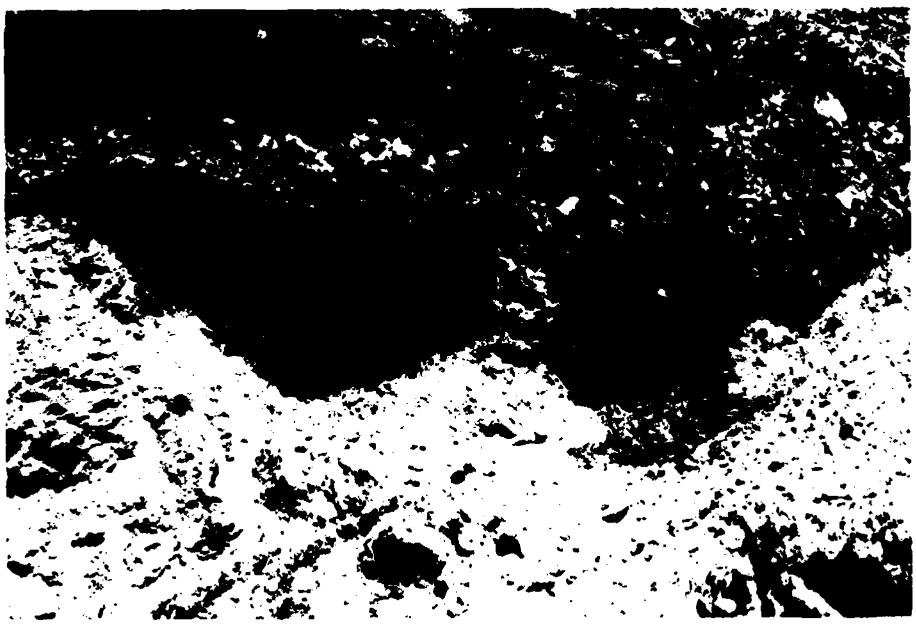

Figure 5. Vertical cut showing limestone pinnacles and clay pockets in quarry near the Medford Cave site

nearby limestone quarry (located approximately 1 mile east of the site) showing a pinnacled limestone surface with clay filling the pockets between the pinnacles; the top of the limestone at the Medford Cave site is similarly pinnacled (shown in the next section). Two limestone

formations are encountered at the site. The basal limestone member of the Hawthorne Formation (Miocene) is a hard, molluscan limestone (about 3.5 ft thick) which partially "caps" the hill under which the Medford Cave system is developed. The Crystal River Formation (formerly known as the Ocala Limestone) of the Ocala Group of limestones (Eocene), which unconformably underlies the Hawthorne Formation, is a soft to very soft, friable limestone. (In many instances, the Crystal River Limestone is composed almost entirely of test of foraminifera and could be classed as a microcoquina.) The known portions of the Medford Cave system are developed in the Crystal River Formation.

The Medford Cave System

12. Figure 6 is the map of the Medford Cave system produced through the joint efforts of SwRI and the Florida Department of Transportation. Note the two portions of the cavity sytem; while connection between the two portions is suggested, no direct connection has been confirmed. Access to various parts of the system is by openings in the bottom or sides of three of the four sinks at the site, such as the Primary Entrance shown in Figure 4. Depths to top of the cave system range from 10 ft (3 m) to as much as 50 ft (15 m). Segments of the cavity system vary in size up to a mean cross-section diameter of about 20 ft (6 m). Two of the larger rooms of the system have unobstructed lengths of 50 ft (15 m) or greater. The cavity system is air-filled with the top of the water table about 66 ft (20 m) deeper than the deepest mapped cave level.

13. There are two major trends to the main part of the cavity system: N45°W and N70°E. A third trend, N45°E, is defined by a line passing through three of the sinks.* The first trend above is approximately parallel to the axis of the Ocala Uplift. The second trend is roughly the same as a mapped fracture (joint) trend through the Big Room.

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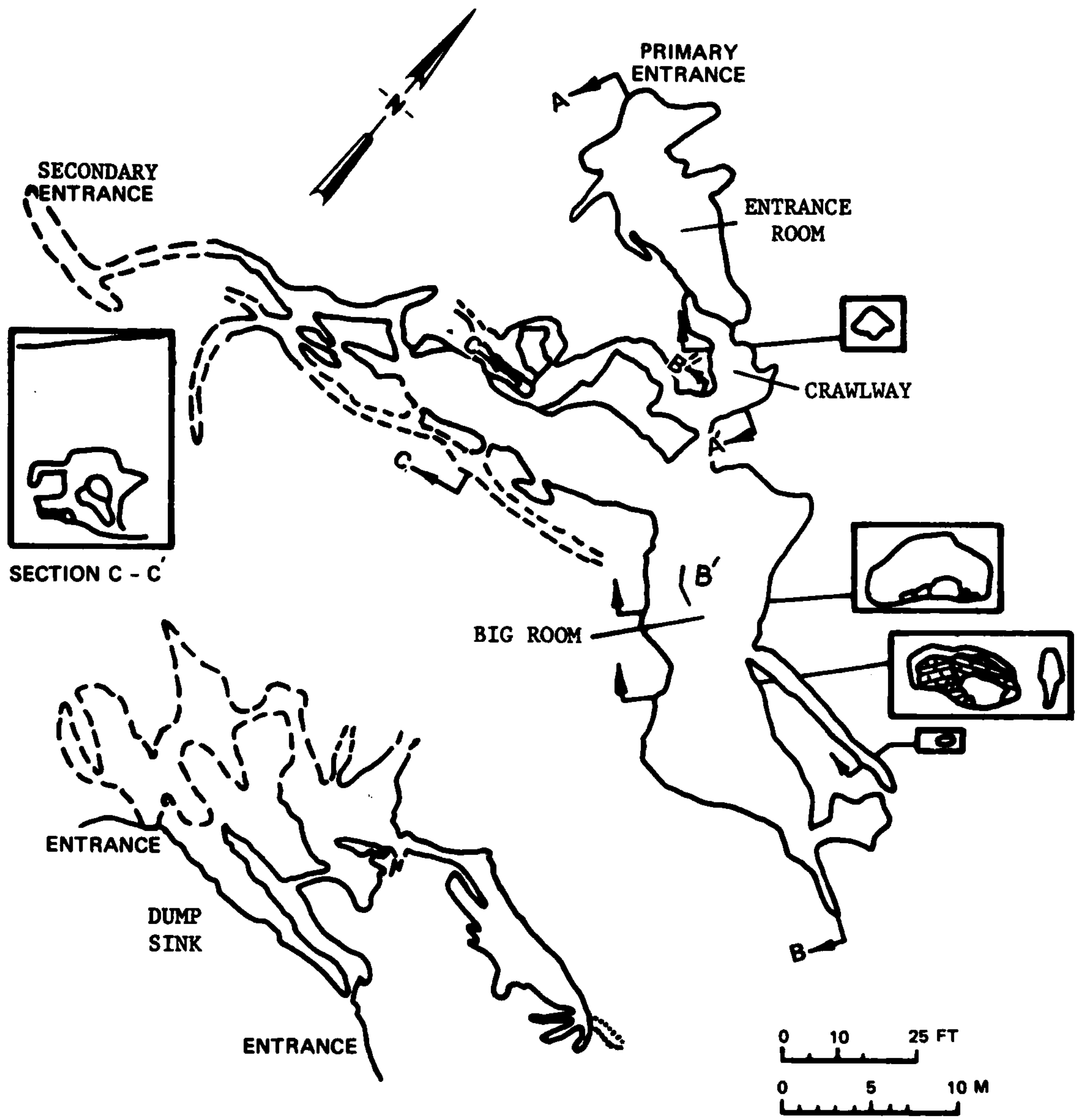
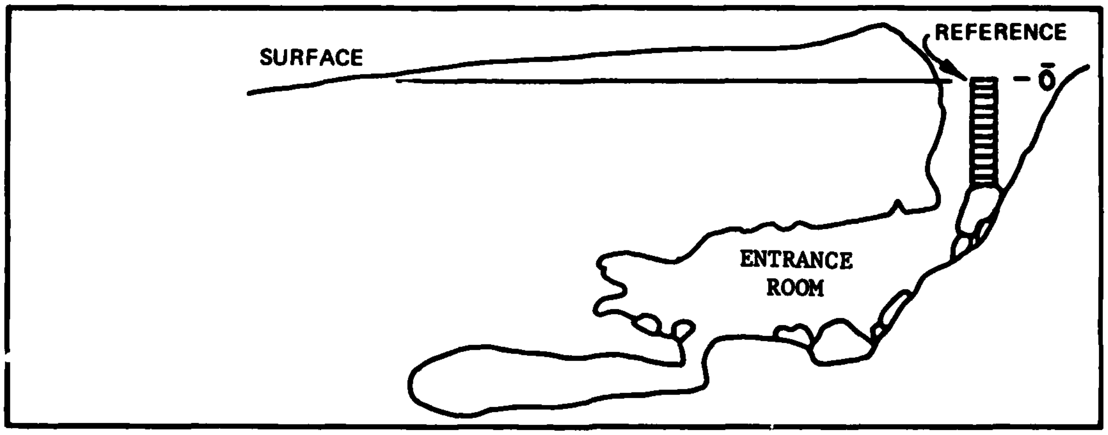
* A small sink located about 100 ft (30 m) to the southwest of the Secondary Entrance is not shown in Figure 6a.



a. Plan view of cavity system with selected cross sections

Figure 6. Cavity map with selected cross sections (Continued)



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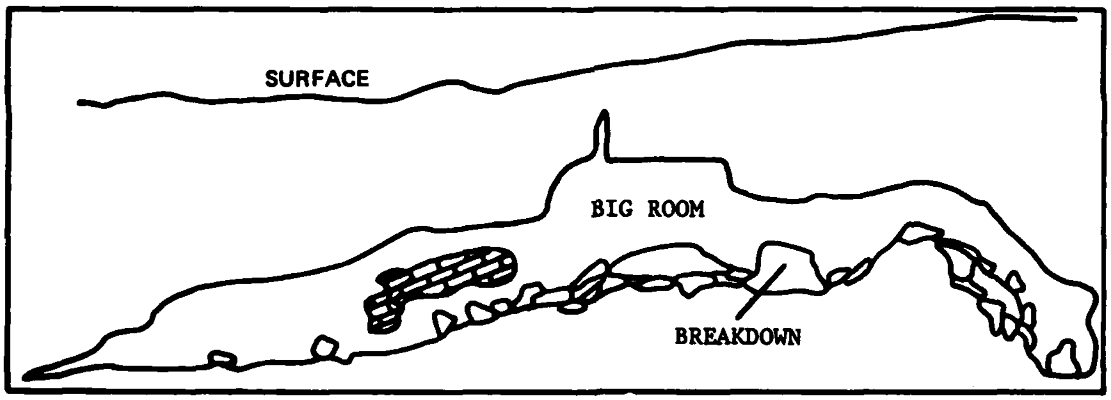

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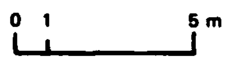


b. Cross-section views of Entrance Room and Big Room

Figure 6. (Concluded)

These observations are consistent with the general observation that cavity systems in Florida tend to develop along fracture (joint) trends (Faulkner 1970).

14. The Medford Cave system is young and has no cave formation, although some limestone surfaces have a very thin calcite coating. There are petromorphs in the form of chert protrusions from the cave walls, and there are large breakdowns or roof falls. Figures 7 and 8 show the Entrance Room and the Big Room and some of the breakdowns.

Figure 7. Entrance Room, Medford Cave

Figure 8. Big Room, Medford Cave

Site Grid System and Topographic Survey

15. In planning the site grid system, use was made of a surface benchmark established by the SwRI in their work at the site and also of the center of the top rung of the steel ladder in the Primary Entrance. These references allow the present grid system to "tie-in" to the subsurface map in Figure 6. Also, it will be possible to correlate survey results with the results of SwRI work at the site if desired.

16. The basic grid system established consisted of N-S and E-W lines with survey reference markers every 20 ft (6.1 m). Over a substantial portion of the site, intermediate positions were also located (i.e., every 10 ft or 3 m). At every survey position a 2- by 2- by 12-in. wooden stake was driven flush with the ground surface, and every 20 ft an offset reference survey stake was placed and labeled with north and west coordinate locations. Station (0,0) is the southeastern corner of the survey grid, and station (260,260) is the northwestern corner, where the first number is the north coordinate and the second number is the west coordinate in feet relative to point (0,0). The survey area is 6.76×10^4 ft^2 (6280 m^2) or 1.55 acres. Figure 9 shows the survey grid relative to the cavity system. The four easternmost N-S survey lines as well as the northernmost E-W survey line were set with transit and tape with great care. The remainder of the grid was established with tapes and chaining pins in the usual manner.

17. Station (0,0) was assigned a reference elevation of 150 ft. The relative elevation of the top of each of the 2- by 2-in. stakes was determined to 0.01 ft (3 mm) by a level survey. Closure error for the entire survey was 0.04 ft. Figure 10 is the resulting topographic map for the site, with a contour interval of 1 ft. Although contours are drawn within the Entrance Sink and Dump Sink, the actual elevations are not well defined in the sinks. The topography approximates an inclined plane dipping from NW to SE. The grid layout and topographic survey required about three days for a two-man crew.

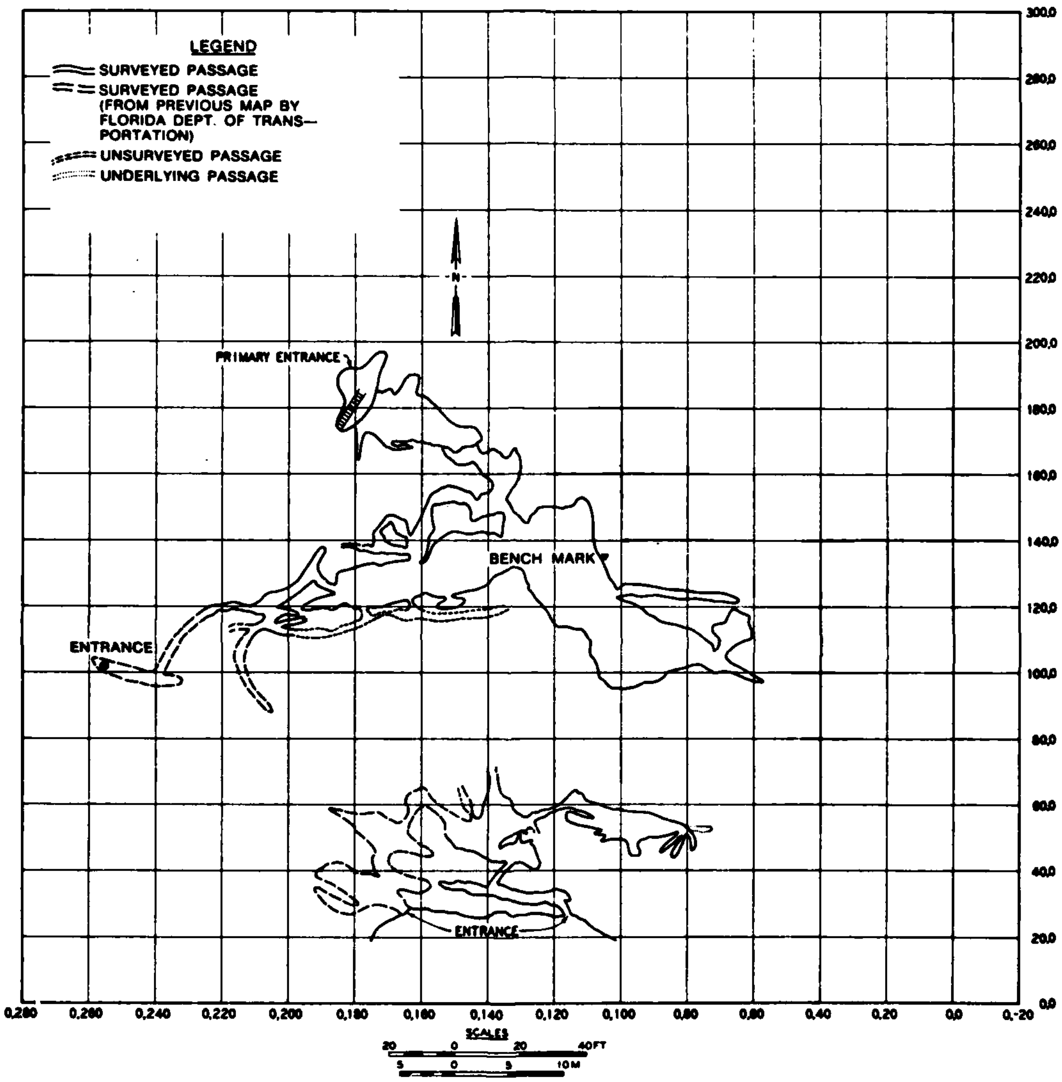
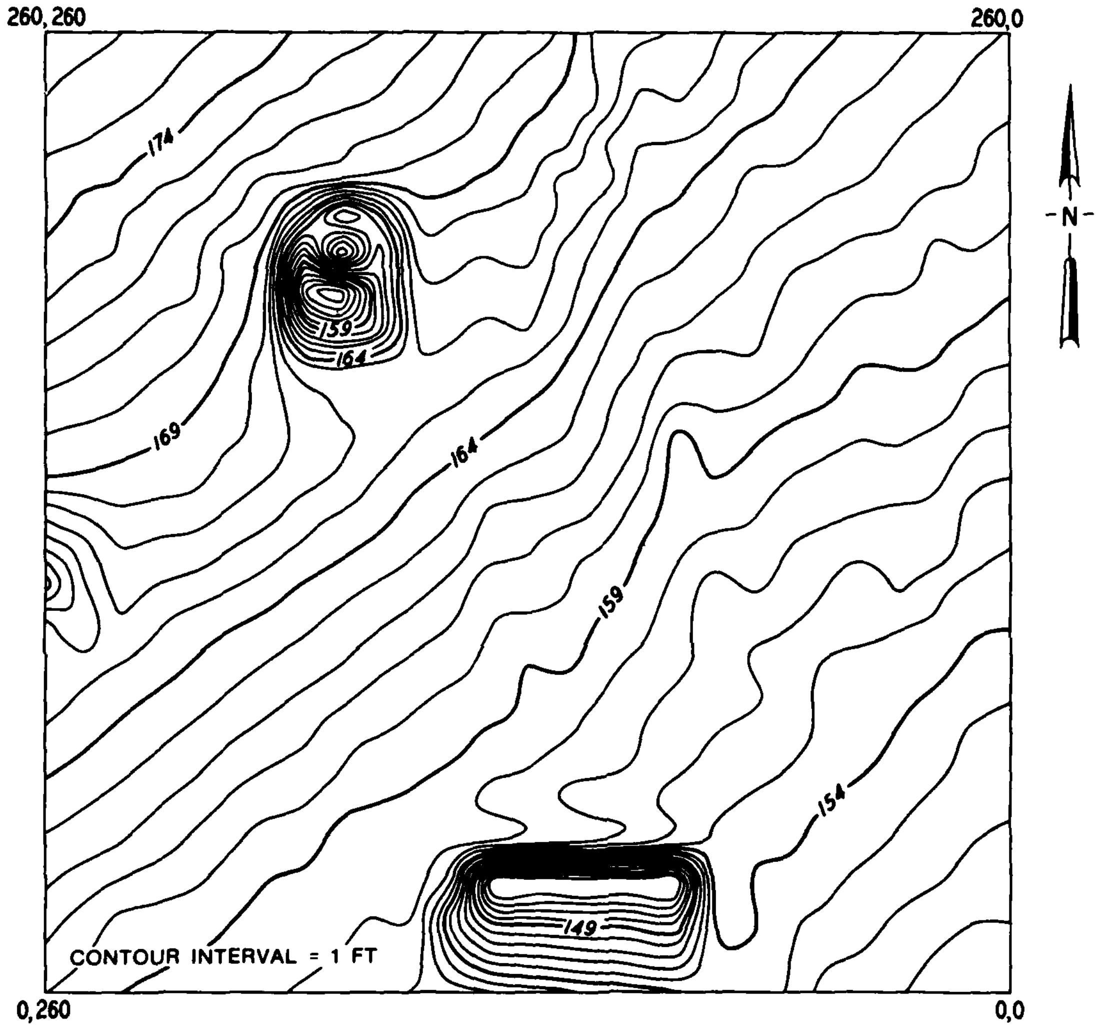


Figure 9. Survey grid, Medford Cave test site



Note: Elevations are relative to point (0,0), with an assigned elevation of 150.00.

Figure 10. Topographic map, surveyed portion of Medford Cave test site

Drilling Program

Drilling phases

18. Drilling at the site was accomplished in three phases and for different objectives. The initial phase of drilling consisted of borings C1 through C9 and L1 through L3, and the primary objective of this phase was to obtain boreholes for subsurface geophysical survey methods; a secondary objective was geologic information. The second phase of drilling consisted of borings E1 through E16 and the objective was to obtain a detailed geologic cross section along a N-S line at the site. Borings E1 through E16 were typically 15 to 32 ft (4.5 to 10 m) in depth and spaced every 10 ft (3 m) along the 80 W line. Borings E17 through E25, the third phase, were verification borings placed to investigate geophysical anomalies. Figure 11 shows the locations of all the borings.

Results

19. All borings except C4, C7, and C8 were cored and logged in detail. The core logs are presented in Appendix B. At boring C7, soil samples were obtained and Figure 12 presents the results of density and water content tests on those samples. Figure 13 presents the air-dried densities of limestone samples from boring C6. Note that in the 30- to 40-ft (9 to 12 m) depth range, either cavities or soft zones were encountered in borings C6 through C9.

20. Specific boring logs from the verification phase of drilling are presented and discussed in connection with the results of the geophysical surveys. Results of the second phase of drilling (E1 through E16) were used to prepare the detailed geologic cross section shown in Figure 14. Note the limestone pinnacles and clay pockets in the northern portion of the section, similar to those shown in Figure 5. Zones of chert, commonly with large limestone-filled porosity, as much as 1.5 ft thick were encountered in several borings, and the chert commonly occurs just above a cavity or zone with little or no core recovery. Five definite tool drops occurred along the section, the largest being about 3 ft, although numerous zones were encountered where the rock was

very soft and little or no core was recovered. Some of these very soft zones may have been clay-filled cavities.

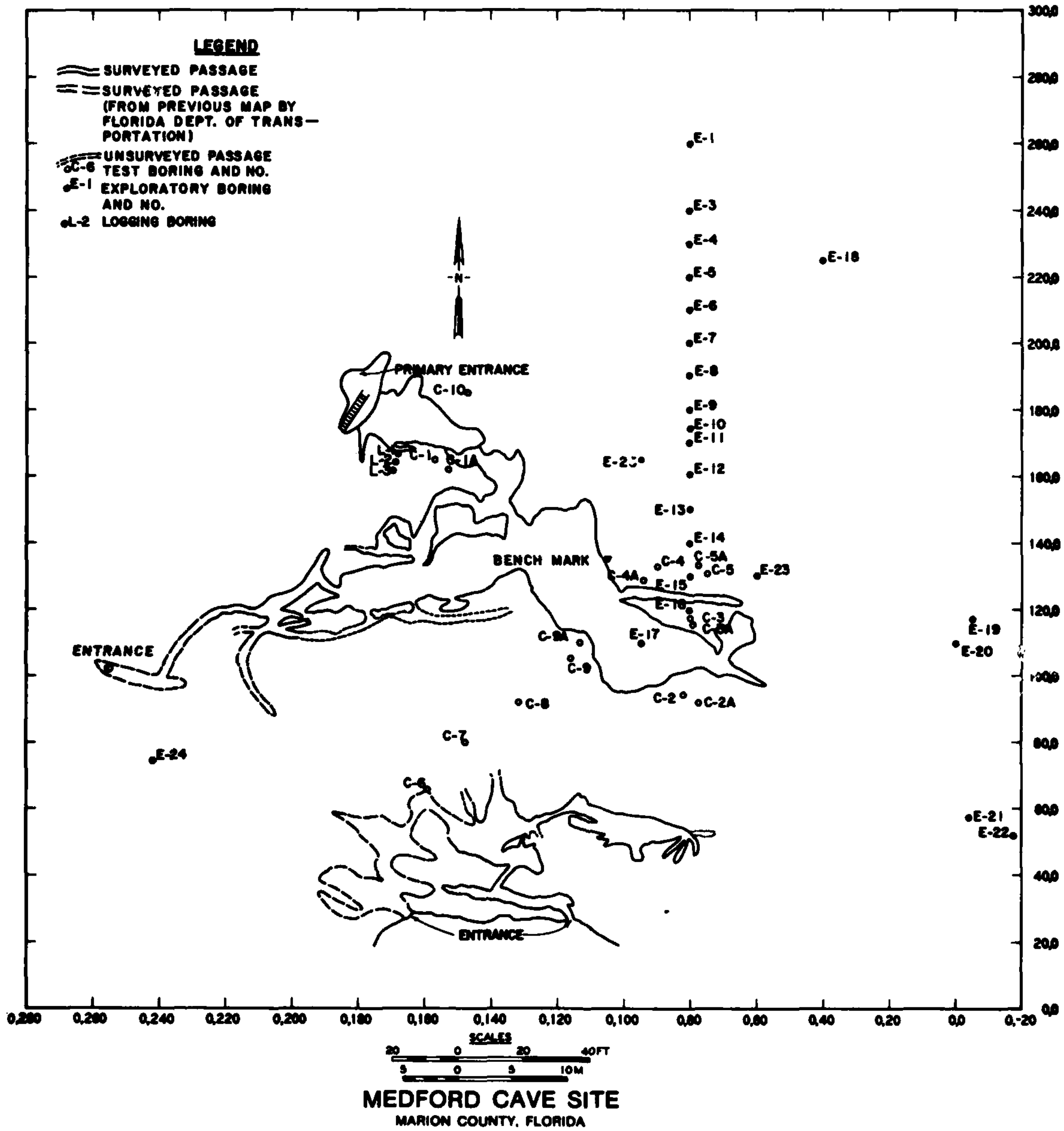


Figure 11. Boring locations

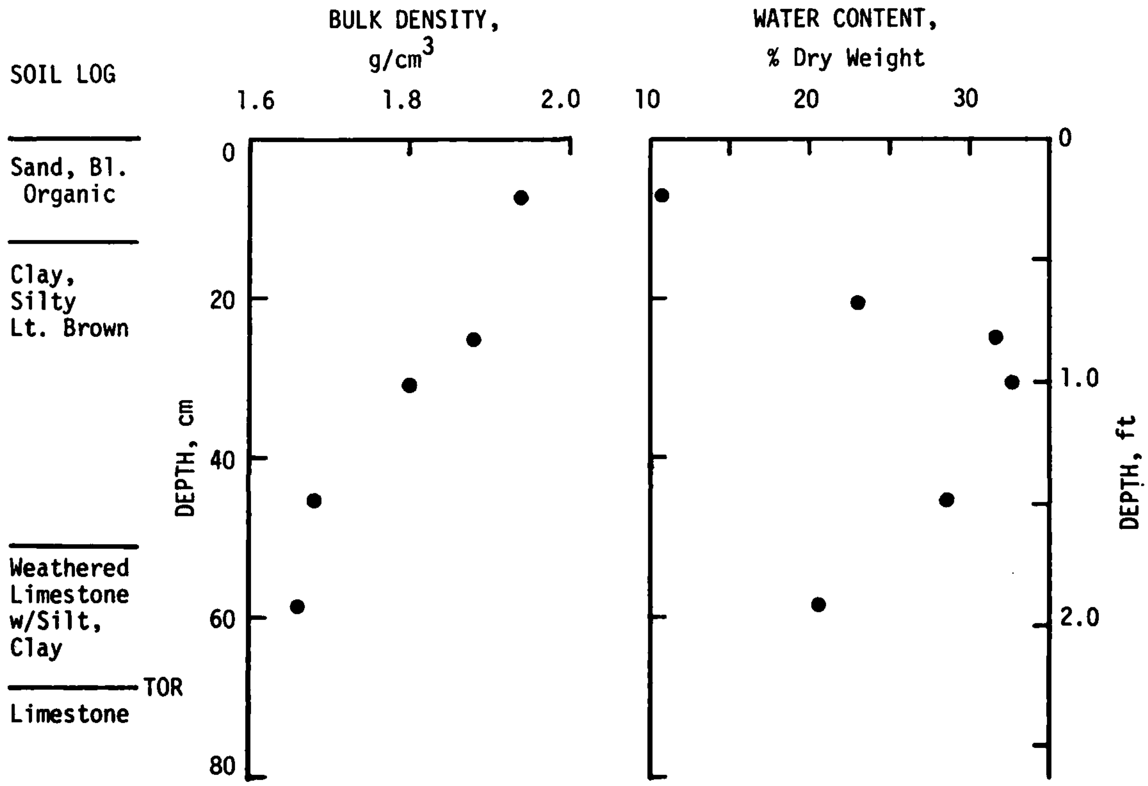


Figure 12. Soil log and properties from boring C-7

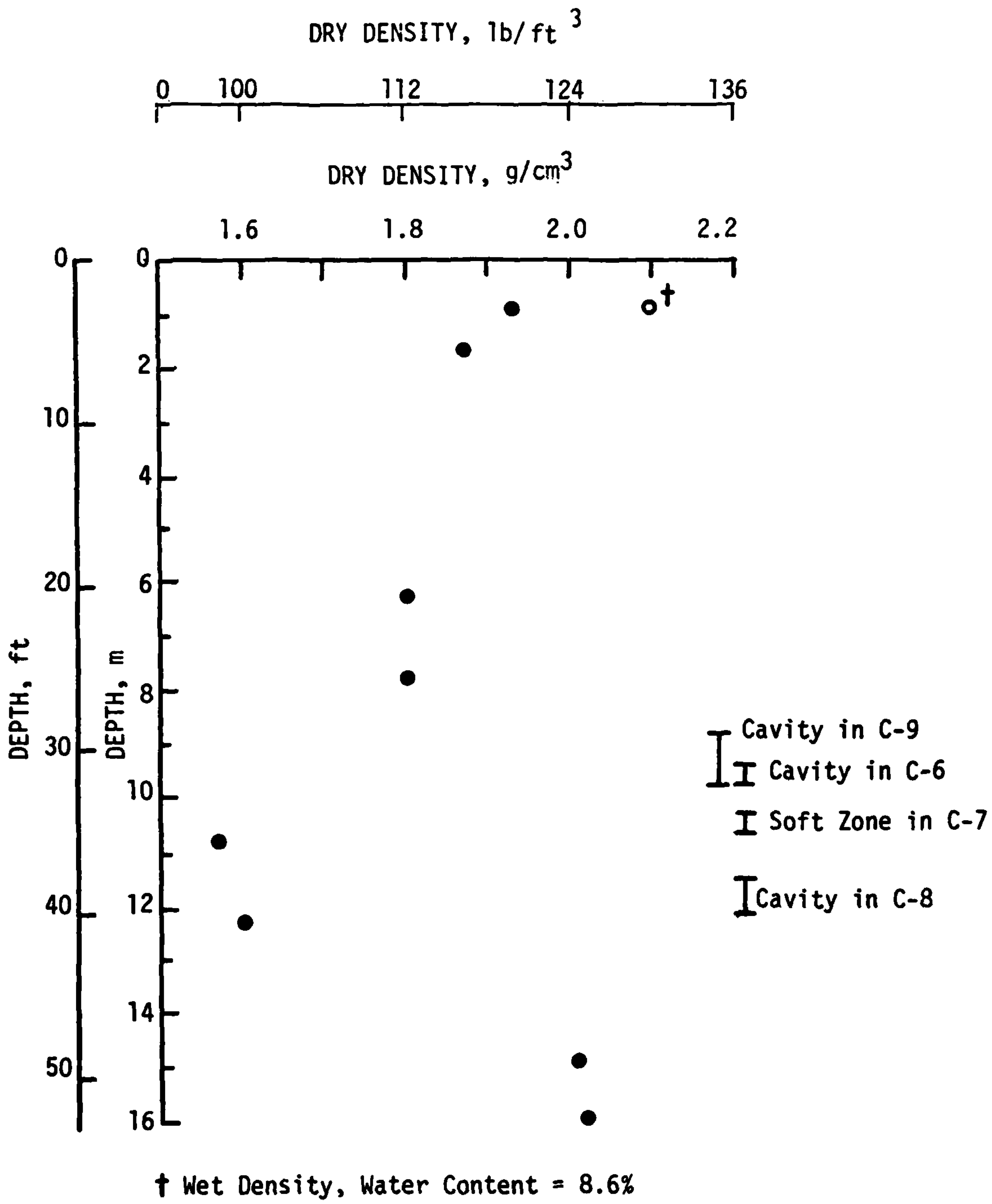


Figure 13. Limestone densities, boring C-6

PART III: MAGNETIC SURVEY

Basic Principles

21. Magnetic surveying is a potential field method* in which components of the earth's magnetic field are measured. The presence of magnetic materials in the subsurface perturb or produce anomalies in the measured field. For cavity detection and delineation, the primary application is hypothesized to be for clay-filled sinks or clay pockets and for clay-filled cavities, because clays typically have a higher magnetic susceptibility than the host carbonate rocks (McDowell 1975, Burton and Maton 1975). The presence of an air-filled cavity in limestone would itself produce an immeasurable small anomaly. Of course, the presence of ferrous metal objects will produce large magnetic anomalies and their presence at a site may interfere with successfully carrying out a magnetic survey.

22. It is beyond the scope of this report to present an extensive review of the magnetic method (see Telford et al. 1976), and since the application discussed here is entirely qualitative, such a review is unnecessary. The units used in magnetic surveying are the gamma (γ), where $1\ \gamma = 10^{-5}$ oersteds. For reference, the strength of the earth's main dipolar field is about 0.5 oersteds or 50,000 γ. Since clays generally have higher susceptibility than limestones, a clay-filled cavity should produce a magnetic high (positive anomaly relative to the background level, i.e., the strength of the earth's field at the site). In the northern hemisphere, the center of the positive anomaly will be shifted to the south of the cause of the anomaly and will be accompanied by a flanking magnetic low displaced to the north (McDowell 1975; Dearman, Baynes, and Pearson 1977; Hooper and McDowell 1977; and Telford

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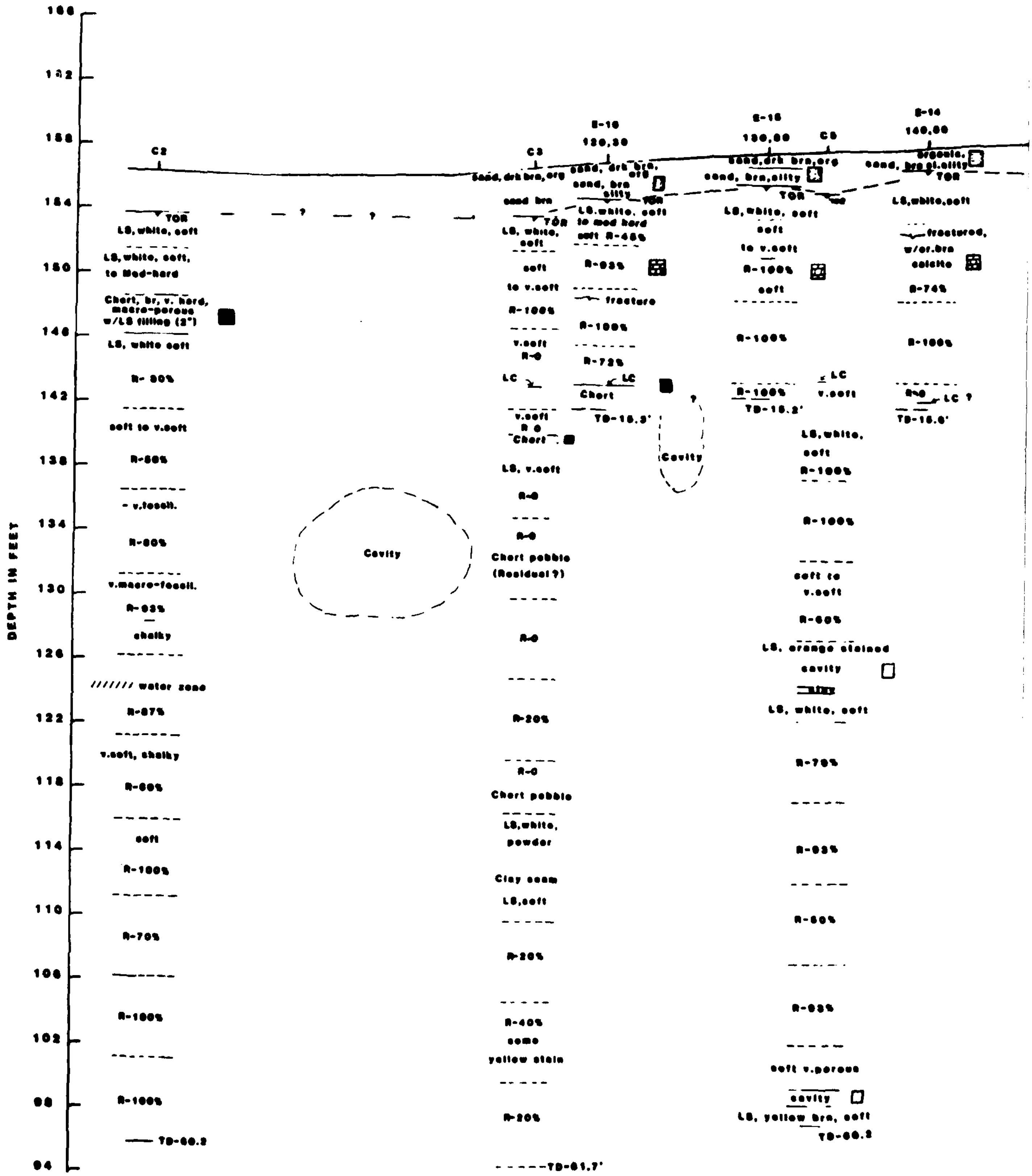
* The potential field geophysical methods, primarily the gravimetric and magnetic methods, are passive (i.e., do not require energy sources of any kind) and measure components of force fields due to the densities and magnetic properties of subsurface materials (Butler 1980 and Telford et al. 1976).



DEPTH IN FEET
C2
C3
B-10
B-15
C5
B-14
TOR
LS, white, soft
LS, white, soft, to Med-hard
Chert, br, v. hard, macro-porous w/LS filling (2")
LS, white soft
R- 80%
soft to v.soft
R-80%
- v.fossil.
v.macro-fossil.
R-93%
chalky
water zone
R-87%
v.soft, chalky
R-88%
soft
R-100%
R-70%
TD-60.2
Cavity
Sand, drk brn, org
sand brn
LS, white, soft
to v.soft
R-100%
v.soft
R-0
LC
Chert
LS, v.soft
Chert pebble (Residual?)
R-20%
LS, white, powder
Clay seam
LS, soft
R-40%
some yellow stain
TD-61.7'
sand, brn silty
LS, white, soft to med hard
fracture
R-72%
TD-15.3'
sand, brn, silty
LS, white, soft
TD-15.2'
soft to v.soft
LS, orange stained
cavity
LS, white, soft
R-79%
soft v.porous
LS, yellow brn, soft
TD-60.3
sand, brn pl.silty
LS, white, soft
fractured, w/or.brn calcite
R-74%
TD-15.0'

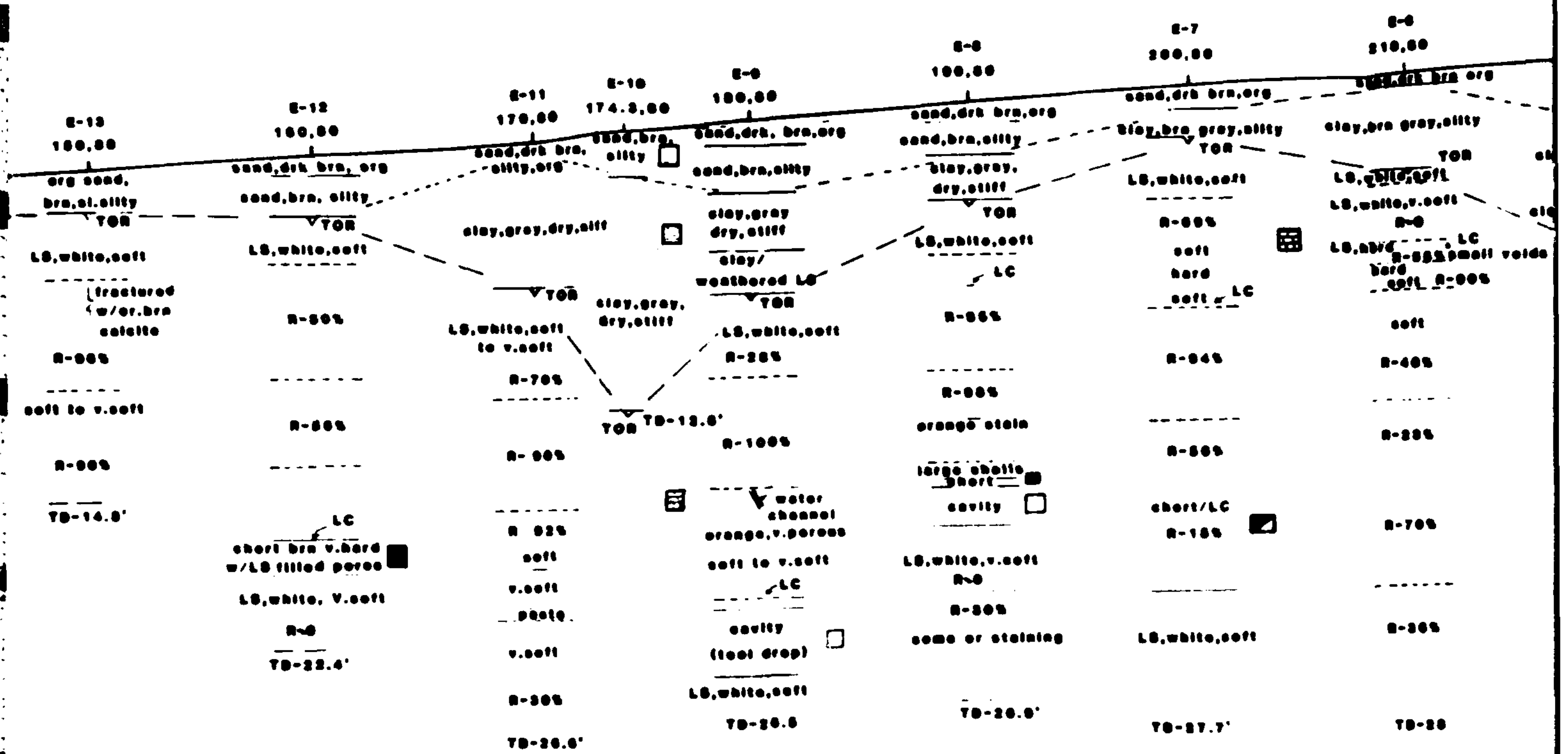
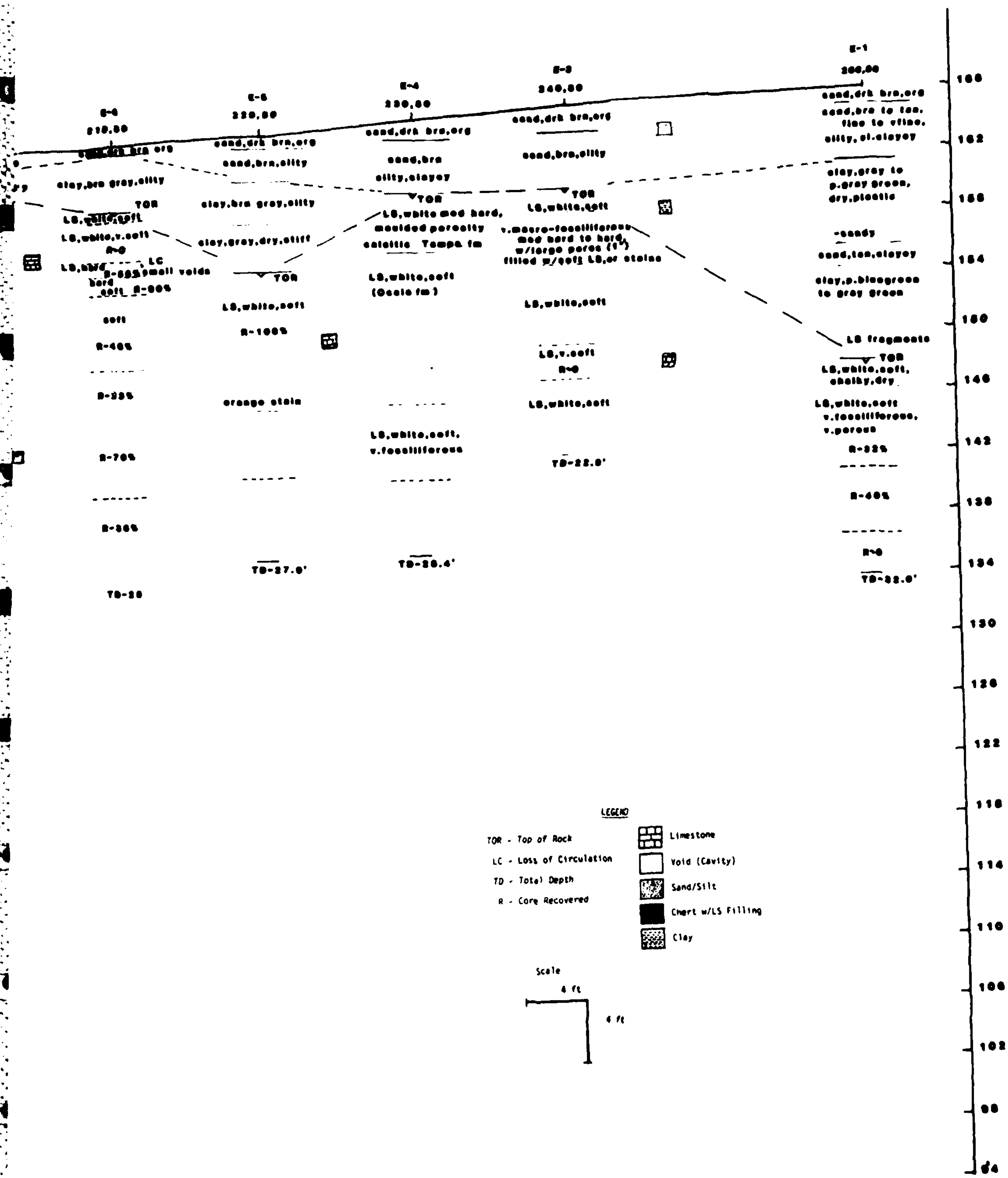


Figure 14. Geological cross section along 80° N-S line

2



TOR
LC
TD-27.0'
TD-26.4'
TD-22.0'
TD-32.0'
TD-30
LS,white,soft
LS,white,soft,
v.fossiliferous
orange stain
LS fragments
LEGEND
TOR - Top of Rock
LC - Loss of Circulation
TD - Total Depth
R - Core Recovered
Limestone
Void (Cavity)
Sand/Silt
Chert w/LS Filling
Clay
Scale
4 ft
4 ft

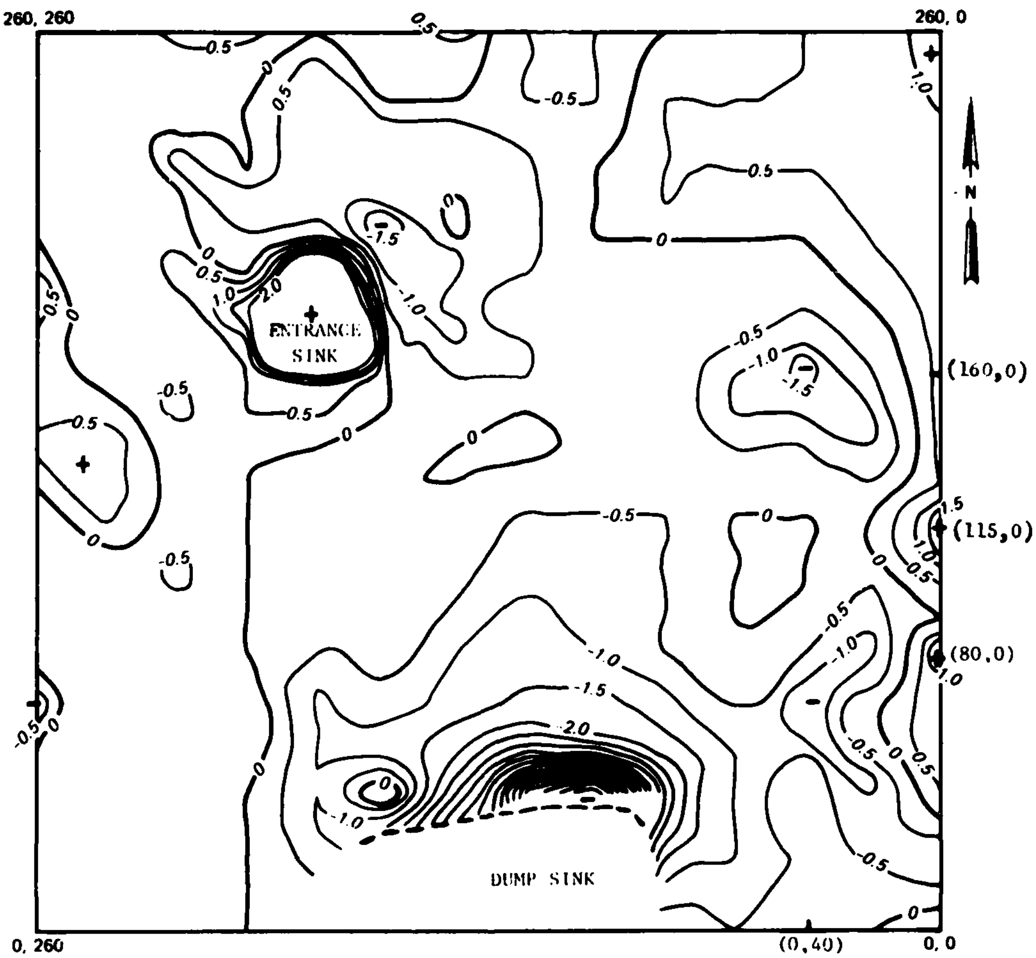
et al. 1976). The magnitude of the flanking lows relative to the magnitude of the highs will depend on the geometry of the anomalous feature and may be absent entirely. For sites with clays generally present over the entire site, the absence of clay in a given area might result in a relative magnetic low anomaly. This could occur, for example, when a limestone pinnacle extends above the clay zone. A clay-pocket (grike) or clay-filled cavity will likely be very difficult to detect magnetically if its dimensions are less than the depth of burial.

Survey Procedure

23. The survey was conducted with a hand-held fluxgate magnetometer (Sharpe MF1-100). The instrument is sensitive to the vertical component of the field and thus must be leveled while making measurements. Data acquired with the instrument are relative in that the zero-level is adjustable. Accuracy of the instrument is probably about ±20 γ, although the scale chosen for conducting the survey could only be read to about the nearest 50 γ. Data was acquired for the most part at 10-ft (3 m) intervals along N-S profile lines separated by 20 ft (6.1 m) in the E-W direction, for a total of about 250 stations. Base stations at the beginning of each profile were reoccupied about every 30 min, but no diurnal variation or drift was observed during the survey. The entire survey required about 8 man-hr over a 2-day period. The only data reduction applied to the data was the subtraction of a constant background field value.

Results

24. Figure 15 is a simplified contour map of the data from the magnetic survey. In some areas of the site, the data vary somewhat erratically and could not be meaningfully contoured. In these areas the variation is generally in the range of -50 γ to +50 γ. Thus the map in Figure 15 shows contours only in areas where a consistent trend in the data defines relatively smooth contours. In Part V, magnetic profiles



NOTE CONTOUR INTERVAL 50γ

Figure 15. Magnetic survey contour map, Medford Cave site

which include all the data will be presented for comparison with microgravimetric profiles and geology.

25. Several positive and negative anomalies are defined in Figure 15. The only anomaly which can be readily explained is the large positive about the Entrance Sink, which is due to the presence of the iron ladder in the sink opening. Although the maximum contour shown is +200 γ, the value observed directly over the ladder is +1700 γ. It is possible that the large-area negative anomaly north and east of the Entrance Sink is a flanking low due to the ladder, although this cannot be confirmed. The large magnetic low to the north and east of the Dump

Sink is difficult to explain. Although there is metal in the Dump Sink itself, no positive values are observed even on the edge of the sink. Likewise the negative centered at (160,40) is of unknown origin. The highs (positive) located at (80,0), (115,0), and (260,0) are of the type expected for clay-filled cavities and pockets.

26. In summary, the magnetic survey results do not appear to reveal anomaly patterns which correlate with known cavity conditions in any way (except for the iron ladder in the Entrance Sink). Individual magnetic profile lines are compared to microgravimetric and resistivity results and to known geologic conditions in Part V.

PART IV: MICROGRAVIMETRIC SURVEY

Basic Principles

27. The gravity method involves relative measurements of the vertical component of the earth's gravitational acceleration. Gravity anomalies occur when lateral density contrasts are present in the subsurface. Like the magnetic method, gravimetry is a potential field method. Microgravemetry refers to high-precision, high-accuracy, and in the present context, to high-resolution applications of the gravity method. Useful references for geotechnical applications of microgravimetry are the reports by Arzi (1975), LaFehr (1979), and Butler (1980). The unit used in microgravimetric surveying is the μGal or 10^{-6} Gal, where $1 \text{ Gal} \equiv 0.01 \text{ m/sec}^2$ (0.0328 ft/sec^2) .

28. Applied to the detection and delineation of cavities, microgravimetry consists of mapping the variation in gravitational acceleration on the surface along profile lines or over survey areas due to the density contrasts represented by air- or clay-filled cavities in rock. Limestone pinnacles and clay pockets (also filled sinks) also represent lateral density contrasts (see Figures 5 and 14) and produce gravity anomalies. Since the density contrast of a cavity feature relative to the surrounding rock will be negative, the gravity anomaly will also be negative. Whether or not the gravity anomaly produced by a specific subsurface feature will be detectable depends on the sensitivity and accuracy of the gravity meter used and jointly on the size and density contrast of the feature in relation to its depth below the surface. Figure 16 (Butler 1980) illustrates the concepts. The curves define the maximum depth to center Z_{max} for which spherical-shaped features with radius R can just be detected at a given threshold gravity anomaly level. For example, the maximum depth at which a spherical-shaped cavity with density contrast $\Delta\rho = -2.0 \text{ g/cm}^3$ and radius $R = 3$ m can be located and still produce a gravity anomaly of -10 μGal is $Z_{max} = 12$ m , or $Z_{max}/2R = 2.0$. Curves are plotted for selected combinations of three density contrasts and two detectability thresholds

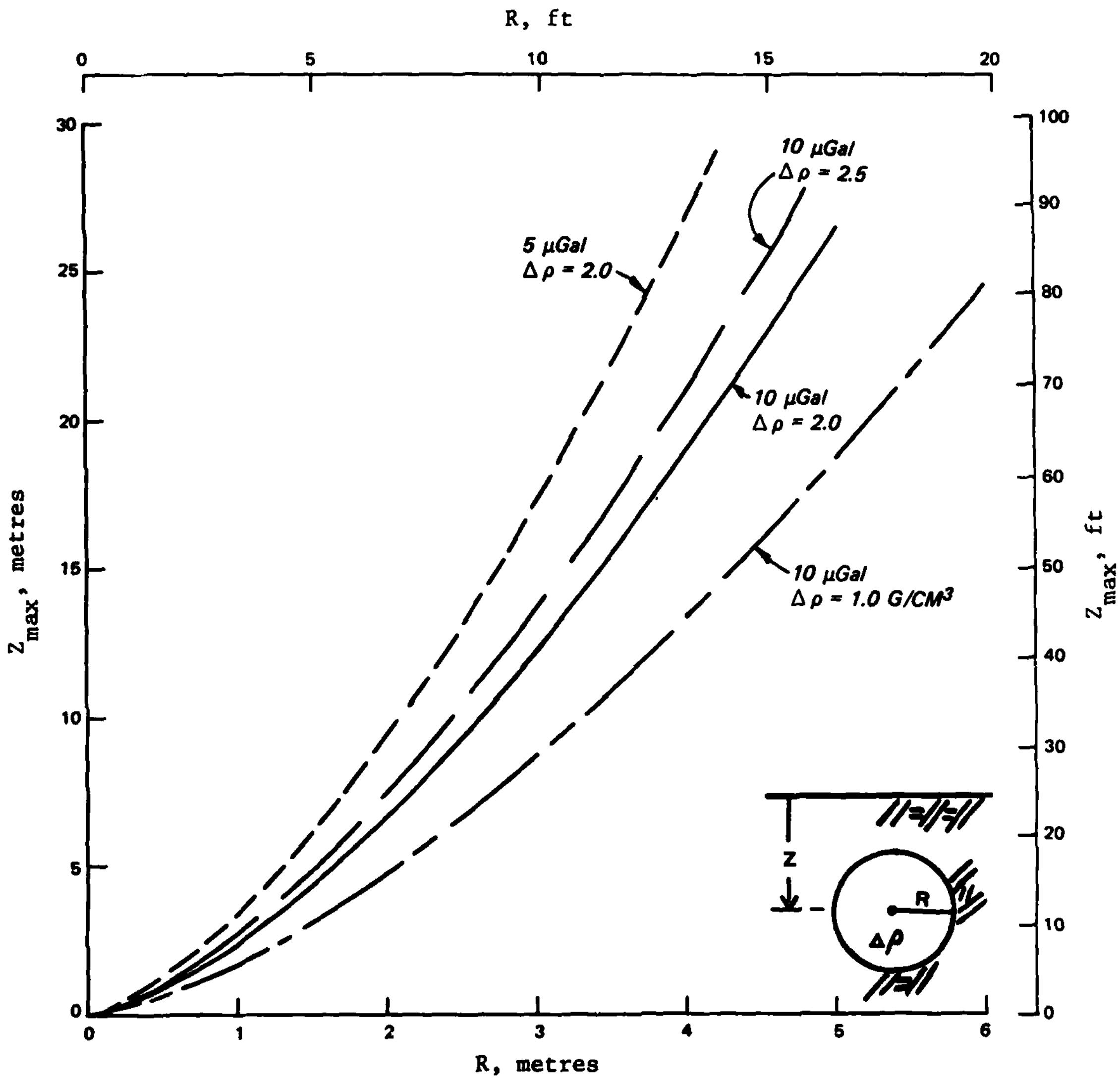


Figure 16. Effect of detectability threshold level (5 or 10 μGal) and density contrast Δρ on maximum depth to center Z_{max} for detection of spherical model of radius R : \ρ is density contrast between spherical model and surrounding material

(5 and 10 μGal). As rules of thumb for predicting the maximum depth at which an air-filled cavity with diameter D in the range of 1 to 5 m can be detected, the following can be used: (a) for spherical-shaped or "compact" cavities maximum depth approximately equal to two times the effective diameter ($Z_{max} \sim 2 \cdot D$); (b) for long horizontal cylindrical-shaped cavities maximum depth approximately equal to six times the effective diameter ($Z_{max} \sim 6 \cdot D$). Real cavities may have geometries intermediate to these two cases and will have associated secondary factors contributing to the total gravity anomaly as noted below.

29. For the Medford site the density contrast represented by air-filled cavity is likely in the range of -1.6 to -2.2 g/cm^3 (Figure 13), while the density contrast of a clay-filled cavity is likely -0.2 to -0.5 g/cm^3. The actual magnitude and areal extent of a gravity anomaly due to a karstic cavity will nearly always be greater that that predicted on the basis of the physical dimensions of the cavity feature itself. This effect is due to natural fractures and lower densities in the rock surrounding the cavity due to solution activity. Note in Figure 13 the lower rock densities in a depth range where cavities are observed.

Survey Procedures

30. Figure 17 illustrates the stations occupied during the microgravimetric survey. Measurements at the 420 stations were obtained with LaCoste and Romberg Model D-4 gravity meter. The Model-D gravity meter has a sensitivity of about 1 μGal, and relative gravity values in a survey can be determined with a precision and accuracy in the range 3 to 6 μGal (Butler 1980). Detailed discussion of the requirements for microgravimetric surveying are given in Butler (1980), and the procedures outlined in this reference were adhered to quite closely with two exceptions: (a) the number of station reoccupations was only 5 percent of the total (20 percent has since been adopted as a recommended value); (b) several programs consisted of long, continuous profile lines. Because of a time limit on the loan of the gravity meter, it was decided

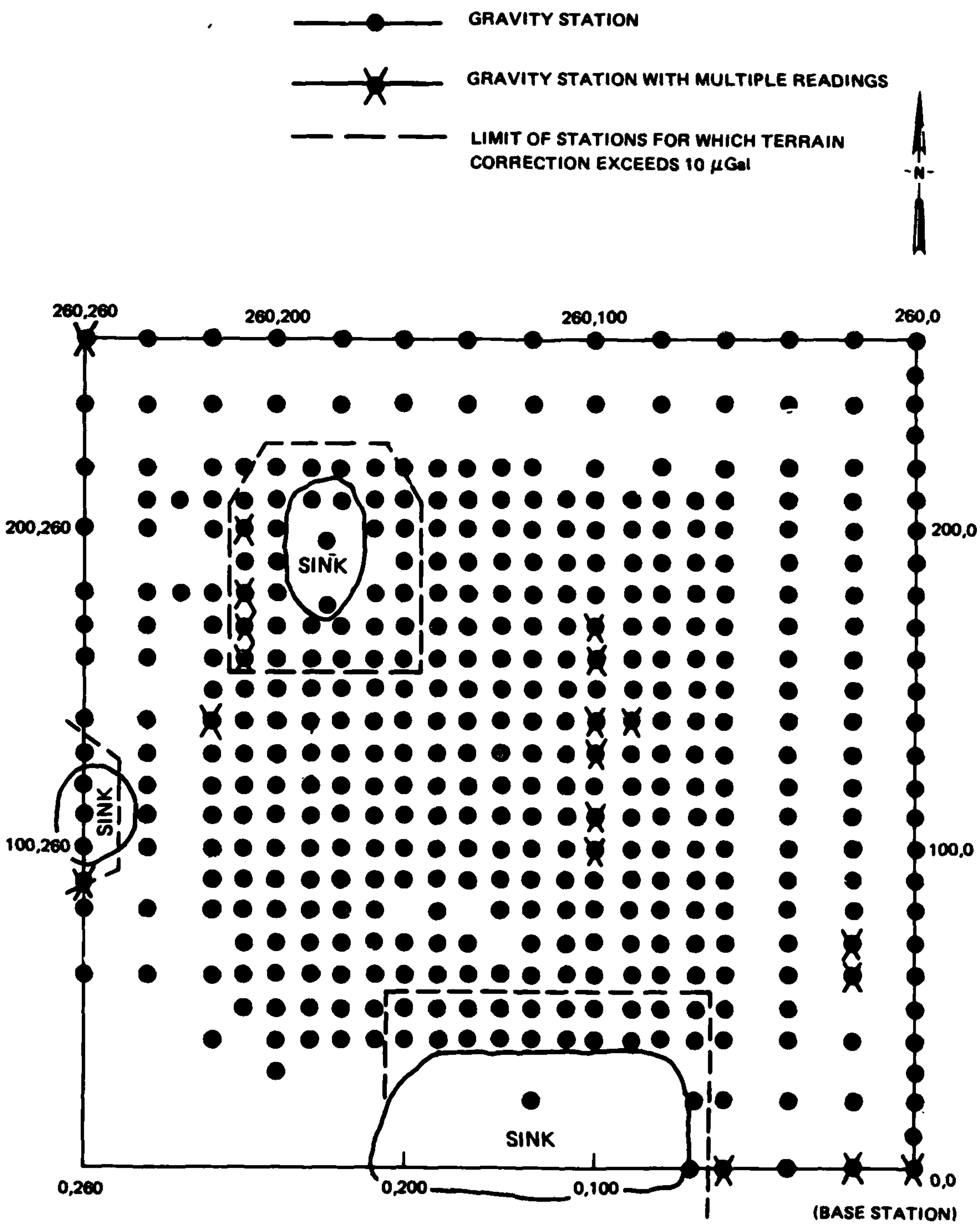


Figure 17. Station locations for microgravimetric survey of Medford Cave site

to sacrifice repeat occupations for a densification of coverage in the area over the known cavities at the site (Arzi 1975). The preferability of short looping or "zigzag" programs to long, continuous programs was noted by Professor Robert Neumann of Compagnie Generale de Geophysique (CGG) in a review of the data from the site following completion of the survey.

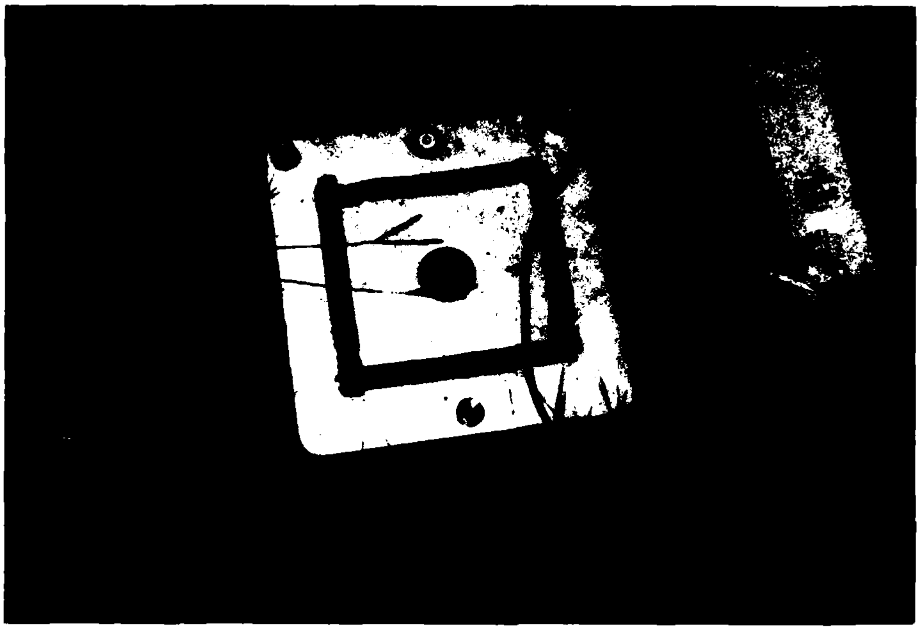
31. Grid point (0,0) was selected as the base station for the survey and was reoccupied once each hour (average rate). A flat baseplate was used for the survey (Figure 18). The baseplate was leveled and the vertical distance from top of the survey stake to top of the baseplate recorded for each station occupation. The gravity meter was then placed on the baseplate and precisely leveled. Then the meter reading and time of the measurement were recorded for each station occupation. In addition, any necessary comments regarding background noise level and stability of the base plate were recorded. Background noise was easily monitored since all readings were made using the capacitive readout meter set on high sensitivity with about 10 μGal/division. The noise level was low during the survey except for the final day, when some averaging of readings was necessitated (which was accomplished by monitoring the meter readings for 1-2 min after achieving the approximate null reading).

32. At night, during the survey, the gravity meter was operated in a tidal recording mode to produce a tidal record for comparison with the field "drift curve" and the theoretical tidal curve for the site. The tidal record was produced about 15 miles from the site.

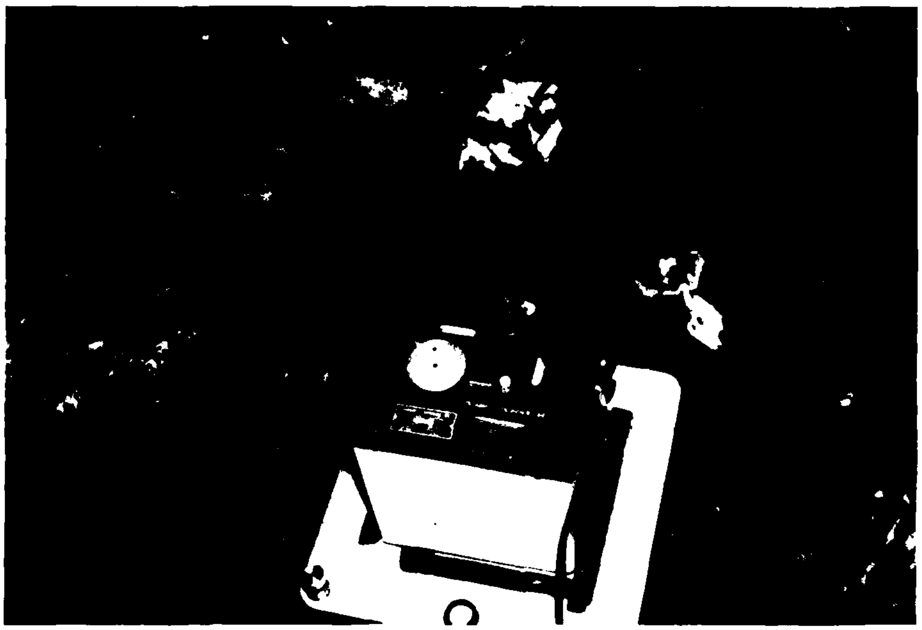
33. The survey required the equivalent of about 7 days for one man. Typical time required per station occupation is 4-5 min, including transport between stations, leveling, reading, and recording data. Productivity ranged typically from 60 to 80 stations per day not counting base station reoccupations.

Data Corrections and Processing

34. Necessary steps for correcting and processing microgravity



a. Flat leveling base plate in place over survey marker



b. Model-D gravimeter in place on flat baseplate

Figures 18. Flat baseplate and Model-D gravimeter

data are discussed in detail in Butler (1980). Assistance with data corrections and processing was provided by Neumann (1979) and several of his colleagues from CGG. The steps are outlined below along with correction equations and relevant comments for the Medford site:

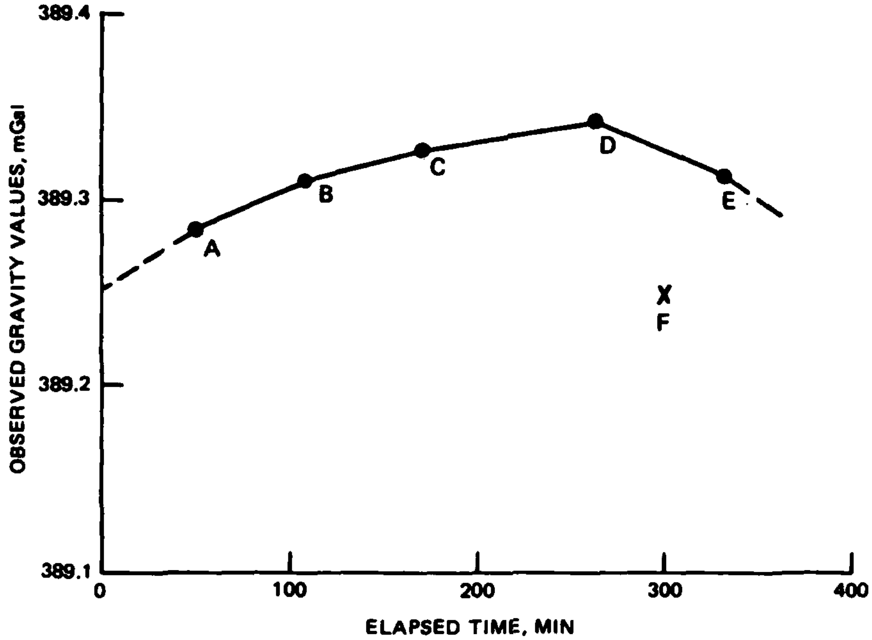
a. Meter factor. The meter factor is multiplied by the meter reading to give a gravity value in μGal . For Model D-4 the factor is 1.08750 in the range used at the Medford site.

b. Corrections for time variations. This is the so-called "drift" correction and compensates for time variations due to drift in the gravity meter readings and to the earth tide changes in gravity. This is accomplished by reoccupying a base station and assuming that the gravity values over the entire site vary in the same manner as the base station reading. Figure 19 illustrates a base station drift curve segment and the drift correction procedure for a station at the Medford Cave site.

c. Latitude correction. This correction compensates for the normal variation in gravity over the earth in an N-S direction. The correction to be applied to each station gravity value is given by $\pm 0.81 \cdot \sin 2\phi \cdot \Delta L$ μGal , where ϕ is a reference latitude for the survey site ($\phi = 29.3$ deg for the Medford site), and ΔL is the N-S distance in metres from the base or reference station for the site. The correction is added if the station is south of the base or reference station, and the correction is subtracted if the station is north of the base. Since station (0,0) was used as a base station, all corrections will be subtracted from the station values since all stations are north of the base (except those on the zero E-W line).

d. Free-air correction. Two corrections are used to compensate for elevation differences between stations. The free-air correction accounts for the normal free-air vertical gravity gradient and is given by $\pm 308.55 \cdot \Delta h$ μGal; where Δh is the elevation difference between a station and the reference elevation in metres. The correction is added if the station is higher in elevation than the reference, and subtracted if lower. For the Medford site, the elevation of the base station is used as the reference.

e. Bouguer correction. The Bouguer correction compensates for the fact that the gravity values in a survey are affected by differing masses of material beneath the stations due solely to elevation differences. The correction is calculated with the expression $\pm 41.91 \cdot \rho \cdot \Delta h$



a. Drift curve for portion of microgravity survey (includes instrument drift and tidal variation)

DRIFT RATES

SEGMENT	R(μGal /MIN)
AB	0.43
BC	0.30
CD	0.18
DE	-0.44

DRIFT CORRECTION FOR STATION F

STATION	TIME, MIN	FIELD READING, mGal	DRIFT CORRECTED READING, g_{obs}, mGal
D (BASE)	263	389.344	400.000
F	300	389.250	399.922*
E (BASE)	334	389.313	400.000

$$*g(F)_{obs} = (400.00 - 389.344) + 389.250 - R_{DE}\Delta T$$
$$= 399.906 - (-0.00044)(37)$$
$$= 399.922 \text{ mGal}$$

b. Example drift correction procedure

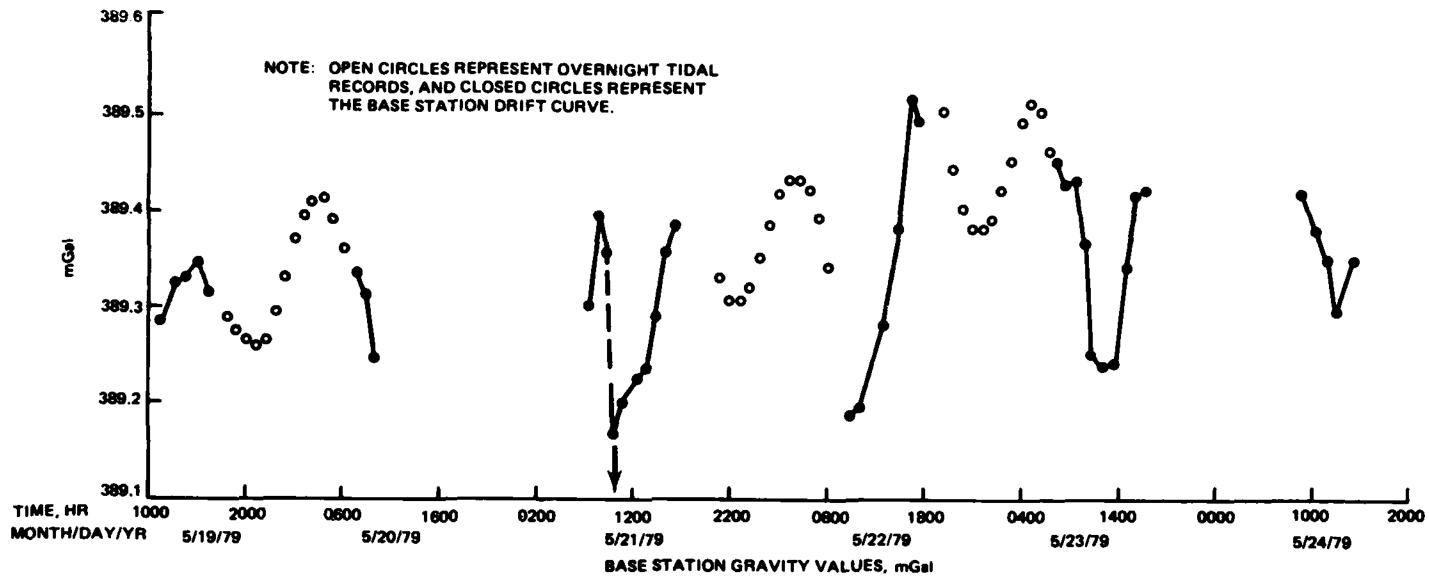
Figure 19. Base station drift curve and drift correction procedure

μGal, where Δh (in metres) is the same as for the free-air correction, ρ is the density of the near-surface material, and the correction is subtracted if the station is higher in elevation than the reference and added if lower. For the Medford site, $\rho = 1.9\ g/cm^3$ was used for the Bouguer correction.

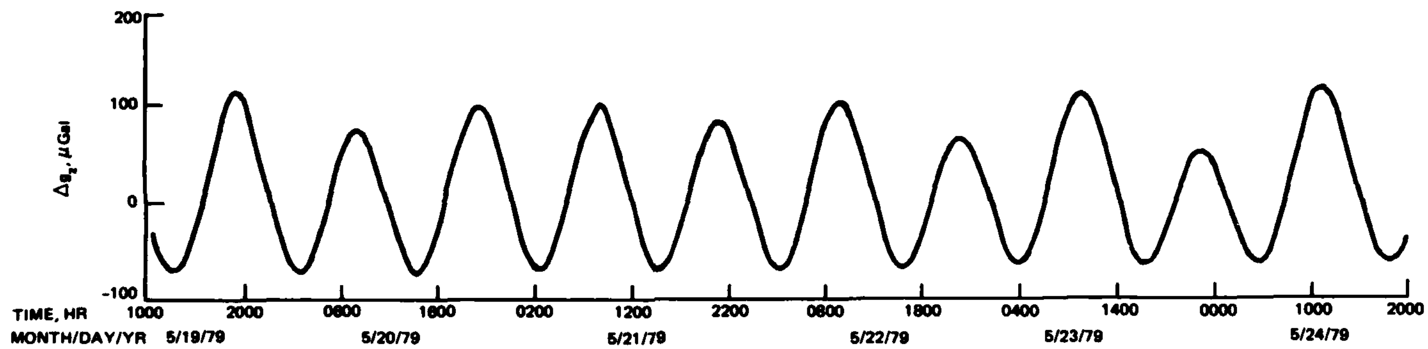
f. Terrain correction. To compensate for the reduced gravity values at stations due to either "hills" or "valleys" in the vicinity, terrain corrections must be determined and added to the station gravity values. The terrain correction is manually determined using a terrain template centered on each station to determine average elevations in sectors around the stations. Terrain correction tables or curves are then used to determine the part of the total corrections for each sector. The sum of the corrections for all sectors of the template gives the total terrain correction for the station. Sample terrain templates and correction curves are given by Butler (1980). Stations at the Medford site for which the terrain corrections exceed 10 μGal are indicated in Figure 17. The gravity value at a station resulting after applying all of the preceding corrections is called the Bouguer anomaly.

g. Data adjustments. Examination of the Bouguer anomaly values can sometimes indicate data which must be adjusted. The adjustment can be as simple as deletion of a clearly bad, isolated value, or sometimes the adjustment may involve raising or lowering all the data values in a given program by a constant amount. The need for this adjustment can be detected by careful examination of repeat readings at a station from different programs or from examination of neighboring station readings in an area with dense coverage, although the exact cause of the "high" or "low" programs is not known. Clearly these data adjustments introduce a measure of subjectivity in the results. For the Medford microgravimetric survey, 10 station values were deleted, and 17 stations belonging to three programs (in the southwestern portion of the survey area) had to be adjusted by +20, -30, and -20 μGal. The small area involved in the latter adjustments was mainly positive (sign of anomaly) and the adjustments did not significantly alter that fact.

35. The base station gravity values presented in Figure 20a represent the majority of the record. The values have been free-air corrected for the height of the base station above the grid marker. Also shown in Figure 20a are the recorded overnight earth tide variations (open circles). Since the overnight tidal records were obtained in a



a. Base station drift curve for part of site microgravity survey with overnight tidal records



b. Theoretical earth tide for site

Figure 20. Field base station drift curve and observed earth tide records for Medford Cave site

different location (a motel room), the segments have been shifted vertically to best fit the base station curve. The phase of the two sets of data agrees very well, but the amplitude variation of the field curve is more extreme. The time marked by an arrow corresponds to a base station reading following a strong jolt to the gravity meter. Because of the frequent base station reoccupations, the recovery period after the jolt is adequately defined. Significant errors can result for less frequent base station occupations in such cases.

36. The theoretical tidal curve for the site, shown in Figure 20b, was computed using the equations of Longman (1959). There is approximately a 4-hr phase difference between the theoretical and measured tidal curves; such phase differences are not uncommon.* Discounting the phase shift, there is good agreement between the amplitudes of the measured and theoretical tidal curve. The long-term cumulative drift (nontidal) of the gravity meter appears to be about 2 μGal/hr, although there are also other nontidal meter drifts much larger than this which are not cumulative. In any event, frequent high-quality base station readings can correct for these time-dependent gravity variations.

Results

Bouguer anomaly maps

37. Figure 21 is a contour map based on the Bouguer anomaly values for stations defining a 20-ft grid. A number of interesting closed-contour features appear on this map, including a significant relative minimum in the center of the map which roughly coincides with the known location and orientation of the Big Room. The Bouguer anomaly map, however, still contains the effects of the regional gravity field, i.e., the gravity field due to the "deep-seated" geologic structure of the area. Indeed, one of the reasons for examining the 20-ft grid

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* For many locations, however, such as Vicksburg, Miss., the agreement between theoretical and measured tidal curves, both in phase and amplitude, is nearly exact.

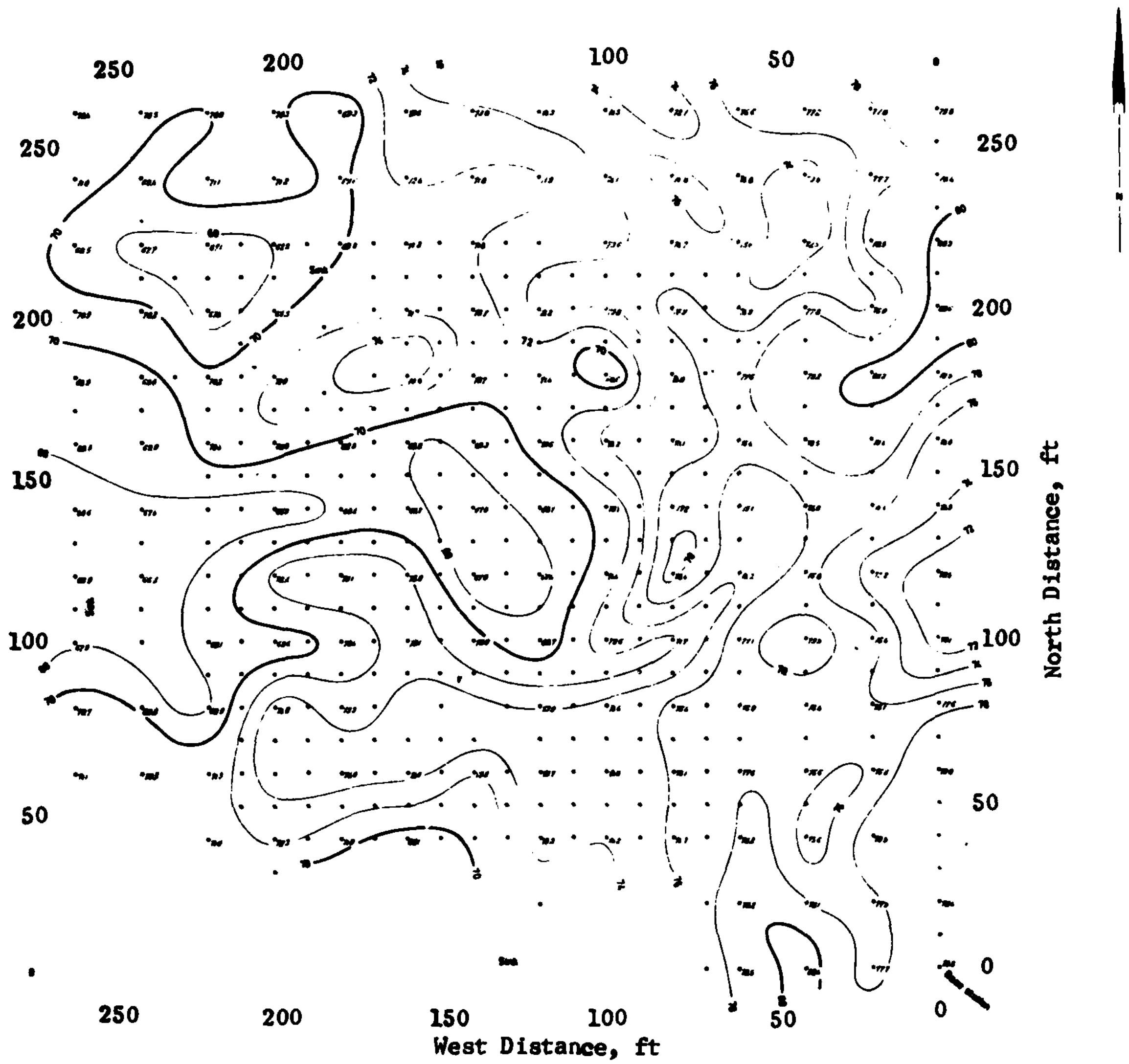


Figure 21. Bouguer anomaly map for Medford Cave site microgravimetric survey (contour interval, 0.02 mGal (20 μGal) and 20-ft station spacing data only)

Bouguer anomaly map is to determine whether a regional field is apparent. It is easily seen by inspection that the gravity anomaly values increase from an average of about 700 μGal on the western grid boundary to about 780 μGal on the eastern grid boundary. Assuming a linear regional variation over the site (i.e., assuming a planar regional field), the field increases from west to east at a rate of 0.3 μGal/ft or 3 μGal/10 ft (~1 μGal/m). For completeness, Figure 22 is the Bouguer anomaly map for

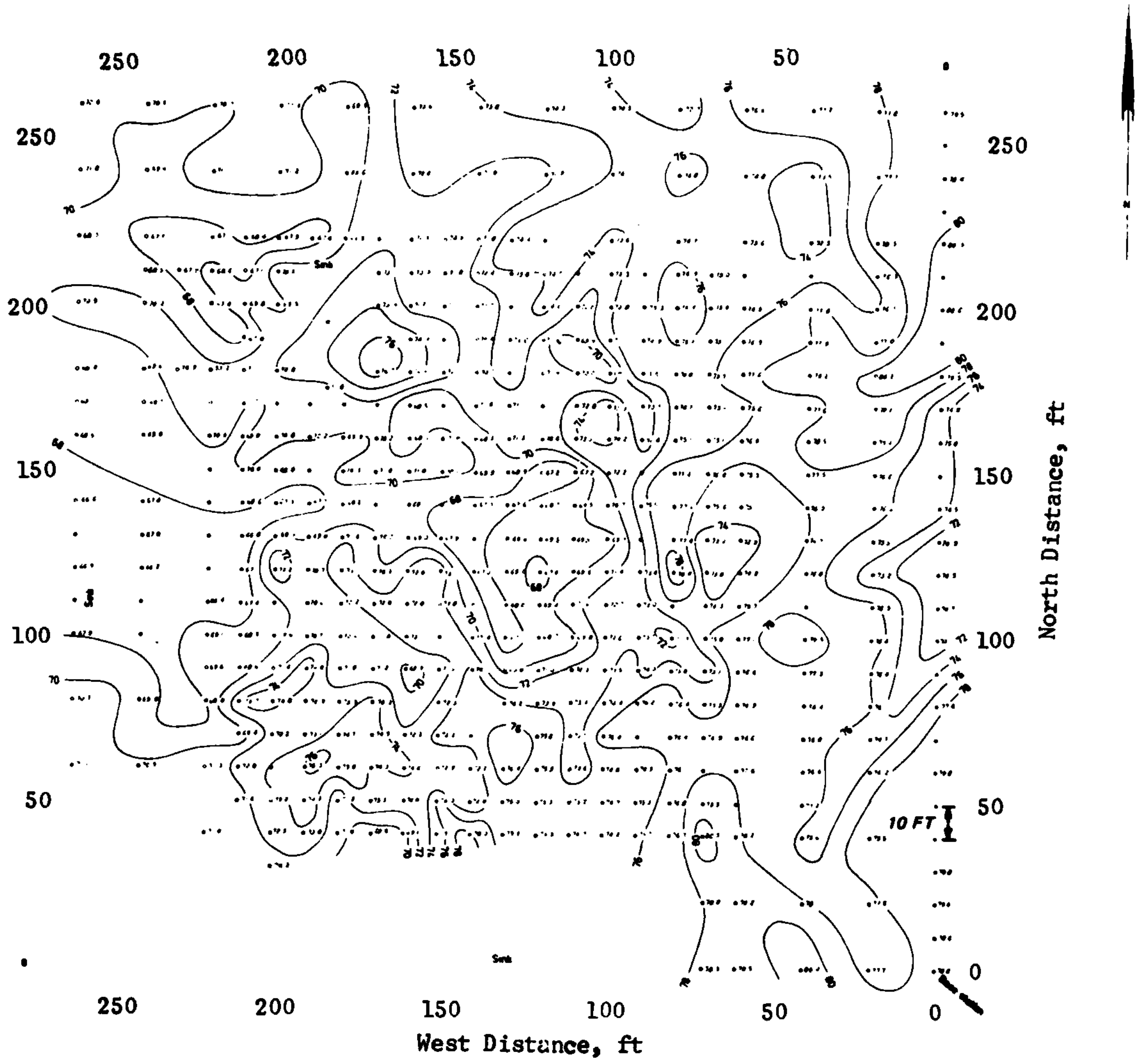


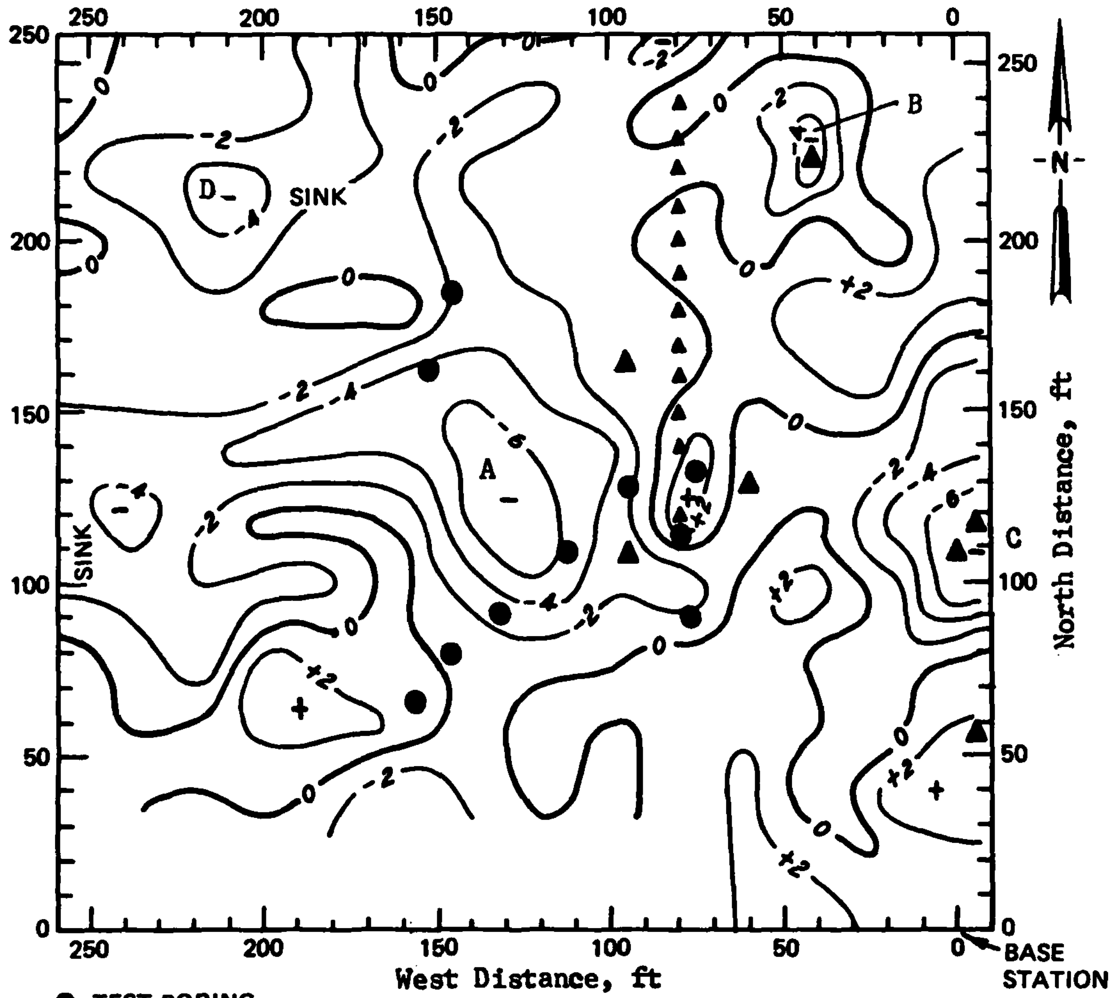
Figure 22. Bouguer anomaly map (10-ft station spacing)

all the gravity stations, and the map is considerably more complex in appearance, as could have been anticipated.

Residual anomaly maps

38. Subtraction of the planar regional field from the Bouguer maps results in the residual anomaly maps shown in Figures 23 and 24, corresponding to Figures 21 and 22, respectively. There are four major negative anomaly features easily noted in Figure 23: (a) a large*

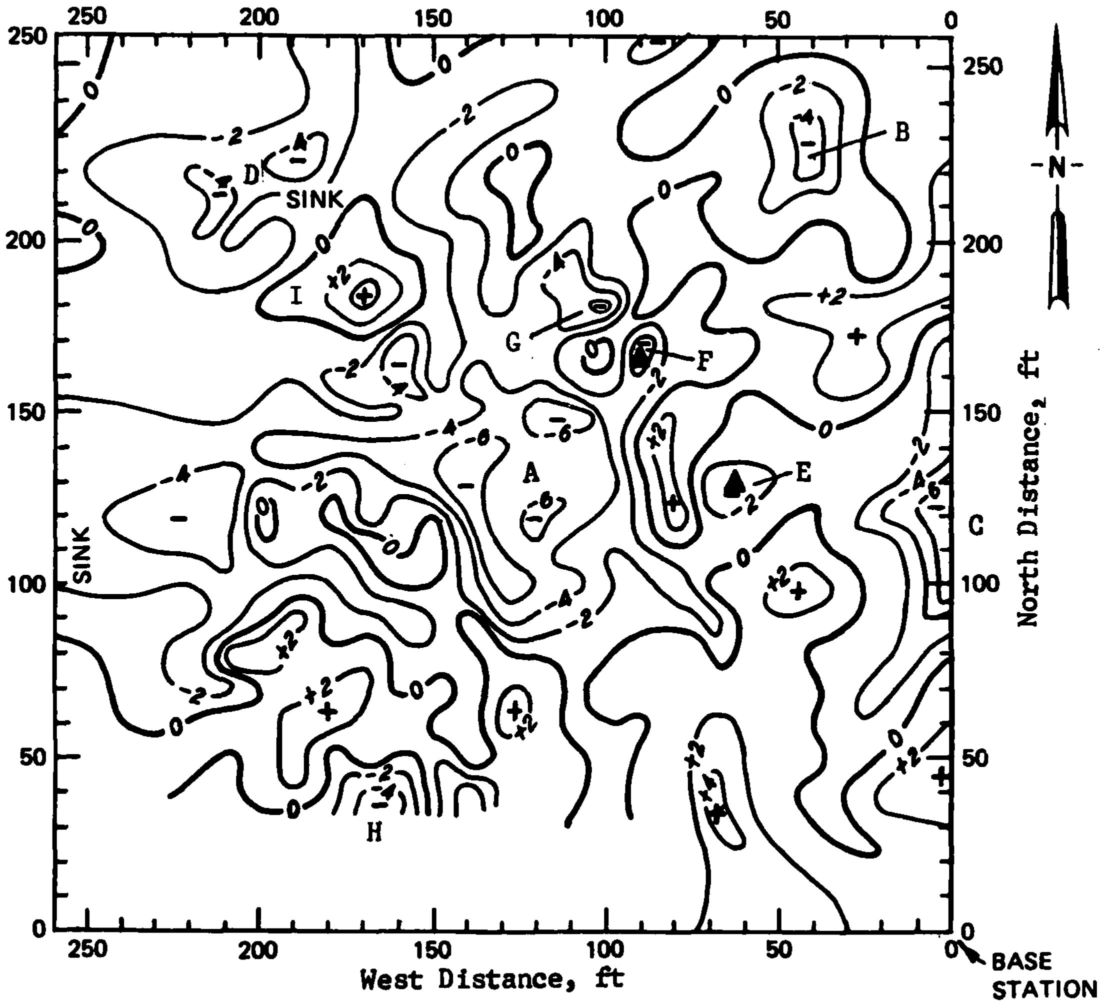
* The term "large" is used in a microgravimetric sense and applies to magnitude or areal extent of the anomaly.



● TEST BORING
▲ EXPLORATORY BORING
▲ CONFIRMATORY BORING
− NEGATIVE GRAVITY ANOMALY REGION
+ POSITIVE GRAVITY ANOMALY REGION

NOTE: CONTOUR INTERVAL = 0.02 mGAL (20 μGAL)
STATION SPACING = 20 FT

Figure 23. Residual gravity anomaly map for Medford Cave site microgravimetric survey (20-ft station spacing)



▲ CONFIRMATORY BORING
– NEGATIVE GRAVITY ANOMALY REGION
+ POSITIVE GRAVITY ANOMALY REGION

NOTE: CONTOUR INTERVAL = 0.02 mGAL (20 μGAL)
STATION SPACING = 10 FT

Figure 24. Residual gravity anomaly map for Medford Cave site microgravimetric survey (10-ft station spacing)

negative anomaly (-68 μGal) in the center of the map with directional trends northwest to southeast and to the west-southwest (anomaly A); (b) a localized negative anomaly (-41 μGal) centered at point (225,40) in the northeast part of the area surveyed (anomaly B); (c) a large negative anomaly (-77 μGal) centered apparently at point (110,0) but extending east beyond the surveyed area (anomaly C); and (d) a negative anomaly (-41 μGal) centered approximately at (210,210) to the northwest of the Primary Entrance (anomaly D).

39. Figure 24 is the residual gravity anomaly map for all the gravity stations (corresponding to Figure 22). All the principal features of Figure 23 are preserved, but large anomalies become more detailed and new small-scale anomalies appear. For example, three small negative anomalies are defined with centers at points (130,65), (165,90), and (180,105), anomalies E, F, and G, respectively, which do not appear as closed features in Figure 22. Anomaly A breaks up into several closed minima within the overall negative values in the area, and similarly for anomaly D. Anomalies B and C are somewhat larger in area in Figure 24 than in Figure 23. Anomaly H, although present in Figure 23, is well defined in Figure 24.

40. On the basis of the results in Figures 23 and 24, confirmatory or verification borings were planned. Specifically, the borings based on gravity anomalies (see Figures 11, 23, and 24) were E18 (anomaly B), E19 and E20 (anomaly C), E23 (anomaly E), and E25 (anomaly F). Borings L1, C1, C1A, and C10 are in the vicinity of anomaly I. Boring E17 was placed in the area covered by anomaly A, specifically to verify the mapped position of the southeastern portion of the Big Room. Anomaly D was inaccessible to the drill rig due to the thick tree cover. Results of correlations of boring results with geophysical results will be discussed in detail in Part V.

<u>Processed gravity maps</u>

41. All of the gravity anomaly maps presented thus far were manually prepared and contoured. While this is a somewhat time-consuming effort (approximately two man-hr to produce a single contour map after data are plotted), the results are often more desirable or pleasing

than automatic computer contour plots, particularly for high-resolution gravity surveys such as discussed here. Manually contoured gravity maps are generally smoother, more "physically realistic" in appearance, and avoid numerous isolated closed contour features which may be defined by only one gravity value. As the spacing between gravity stations in a survey increases, the significance of these differences is obviated to some extent.

42. One of the most often cited advantages of computer-produced contour maps is the total objectivity of the procedure. Figures 25 and 26 are Bouguer anomaly maps for the 20- and 10-ft spacing data sets, respectively, produced by an automatic computer contouring program. Figures 25 and 26 should be compared to Figures 21 and 22, respectively, which are the manually contoured counterparts. In this case, the comparison is quite favorable; there appear to be no significant biases in the manually contoured plots. The primary difference between the manual and automatic contour plots is the contour interval (20 and 10 μGal, respectively), which leads to a more complex-appearing map in the case of the automatic contour plots. All of the primary features of the manually contoured maps are preserved on the automatic contoured maps, although the shapes are altered somewhat and have a more artificial appearance on the automatic contoured maps. Also, as expected, there are more small, isolated, closed features in Figures 25 and 26 than in Figures 21 and 22, although the smaller contour interval accounts for some of them. Considering the computer costs and turnaround time, it is doubtful whether any real time or cost savings could be realized by choosing to produce automatic contoured Bouguer and residual gravity maps. In cases where much larger areas are surveyed on a fine grid like the one used here, automatic contouring would be more efficient.

<u>Derivative maps</u>

43. It is possible to design mathematical filters which operate on gridded Bouguer gravity data to produce transformed maps of derived quantities. The purposes of transformed maps in the present case are twofold: (a) to produce the equivalent of a residual gravity map in a totally objective manner, and (b) to possibly produce an enhancement of

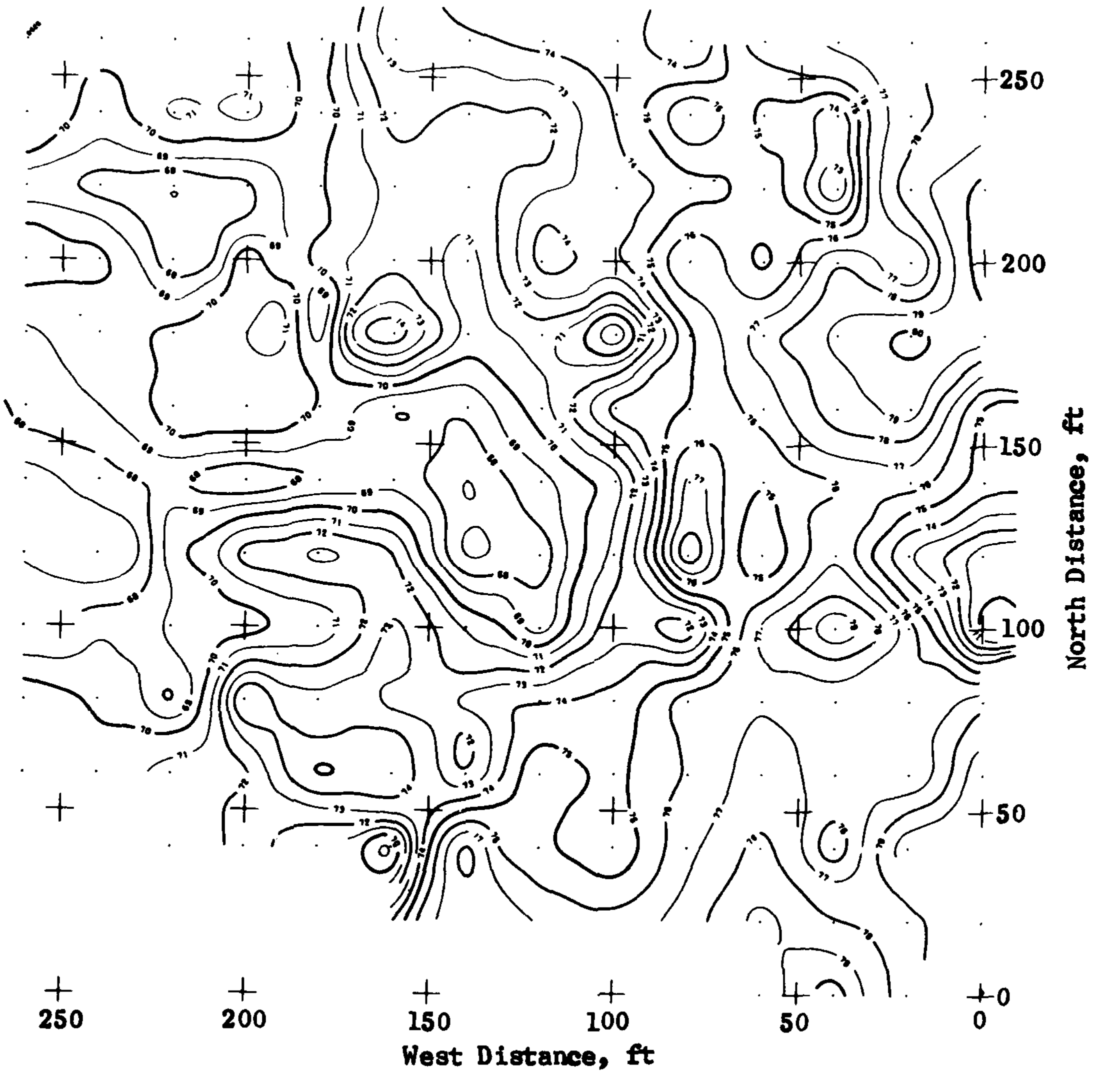


Figure 25. Bouguer anomaly map, 20-ft data, computer contoured; contour interval = 10 μGal

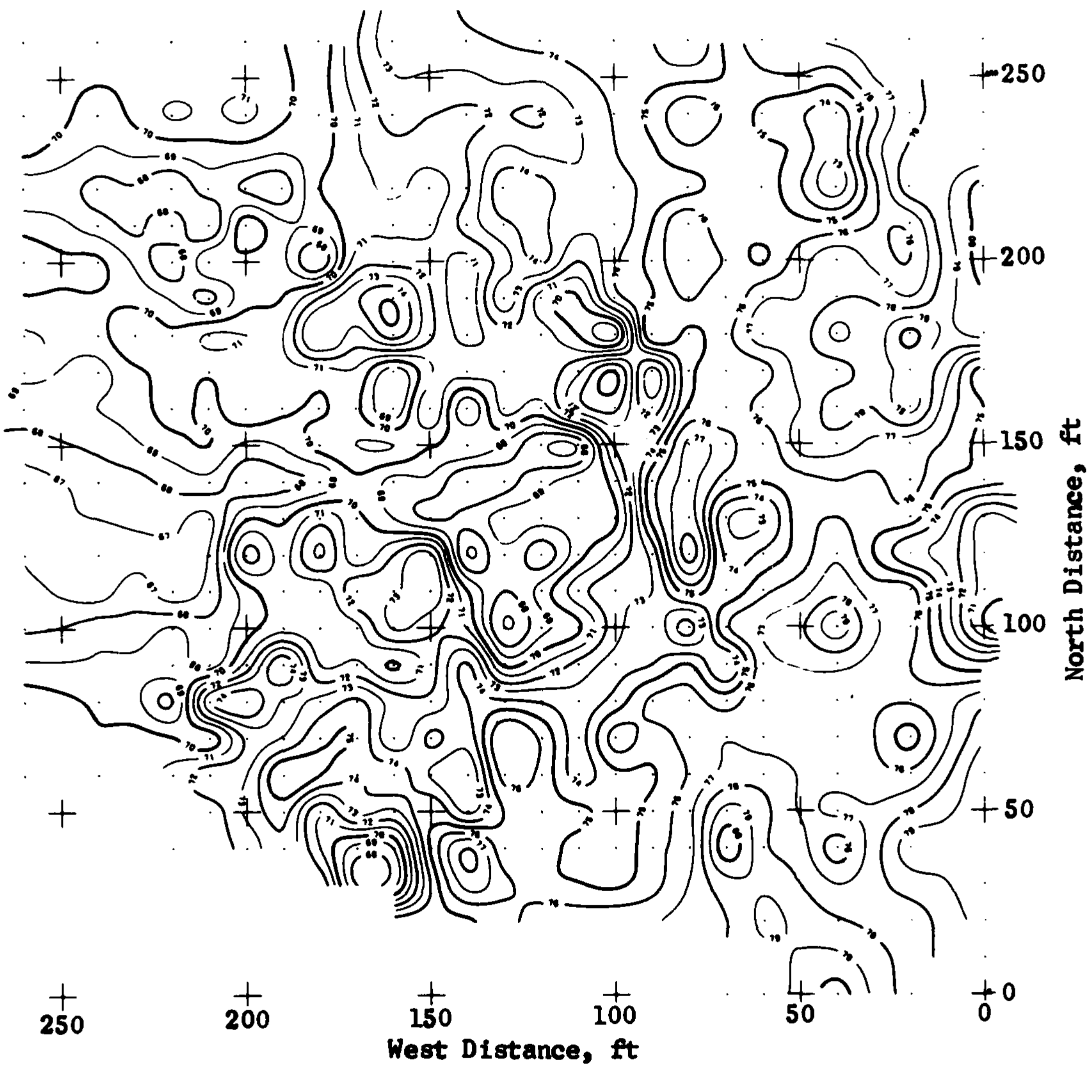


Figure 26. Bouguer anomaly map, 10-ft data, computer contoured; contour interval = 10 μGal

gravity anomalies caused by shallow structures. This general class of transformations is referred to as ring and center point methods, since the procedure involves working with gravity data which lie on various rings which are centered on a particular gravity station. Application of the filter results in a derived quantity for the center point in question. The center point location shifts successively to all gravity stations in the survey. A transformed contour map can then be produced from the derived quantities. Various types of automatically determined residual gravity maps can be produced as well as maps of the first and second vertical derivatives of the Bouguer gravity field. All of the methods involve polynomials of the form $k_o g_o(r_o) + k_1 \bar{g}_1(r_1) + k_2 \bar{g}_2(r_2) + \ldots$, where the k_i represents the weighting coefficients which depend on the type of derived quantity with $\Sigma_i k_i = 0$, g_o is the Bouguer gravity value of the center point, and $\bar{g}_i$ is the average Bouguer gravity on the i^{th} circle with radius r_i about the center point. If a is the station spacing in the grid,* then the possible successive circles have radii a, $\sqrt{2}\,a$, $2a$, $\sqrt{5}\,a$, etc., for $i = 1, 2, 3, 4, \ldots$, respectively.

44. Two types of these filter or transformation operations were applied to the Bouguer gravity data of Figures 21 and 22. The first operation used a second derivative** formula due to Elkins (1951):

$$g_z''(0) \simeq 0.67 g_o(0) + 0.33\, \bar{g}_1(a) - \bar{g}_4(\sqrt{5}a)$$

where a is taken as 20 ft. This formula is designed to combine smoothing with the derivative operation to produce a map closely resembling a residual gravity map. The method is sometimes referred to as the Elkins residual method. Use of the ring at $r_1 = a$ introduces

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* If the data were not acquired on a regular square grid, the data can be contoured and a square grid of data deduced by suitable interpolation.

** $g_z''(0) \equiv \partial^2 g_z(0)/\partial z^2$, where the z-axis is vertically downward and the x- and y-axes lie in the horizontal plane.

a second derivative filtering with coefficients chosen to smooth high spatial frequencies, while the ring at $r_4 = 44.7$ ft is used to approximate a local regional field and the average along the ring is subtracted. Figures 27 and 28 are transformed second derivative maps (Elkins residual) produced from the Bouguer anomaly values on a 20- and 10-ft grid, respectively. The contour values should be considered in a relative sense with arbitrary units. These maps should be compared with the residual maps in Figures 23 and 24.* There is a definite qualitative similarity between the residual anomaly maps and the second derivative maps. Anomalies A, B, C, and D are located and oriented approximately the same as in Figures 23 and 27. The primary differences in the two maps occur near the boundaries where certain assumptions must be made regarding the values outside the survey area in order to perform the ring and center point operations. Counterparts to all the labeled anomalies in Figure 24 can be seen in Figure 28. There are, however, numerous small closed contour features in Figures 27 and 28 which arise due to the numerical procedure. Also, some values were subjectively suppressed in the manually contoured residual maps. The property of the derivative method which tends to try to balance positive and negative anomaly regions can be seen in the second derivative maps. Clearly, the same decisions regarding negative anomaly features and recommended confirmatory boring locations would have been made based on the second derivative maps. An attractive feature about "residual maps" produced by the second derivative procedure is that no assumptions or subjective decisions about the regional field are required. This comparison gives some added confidence in the inspection method for accomplishing the regional-residual separation in such cases.

45. The second transformation operation applied to the Bouguer gravity data is a simplification of a first vertical derivative** (vertical gradient) formula due to Baranov (1975):

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* The units of the two maps are not equivalent. The second derivative anomaly magnitudes should only be viewed in a relative sense.

** $g_z'(0) \equiv \partial g_z(0)/\partial z$.

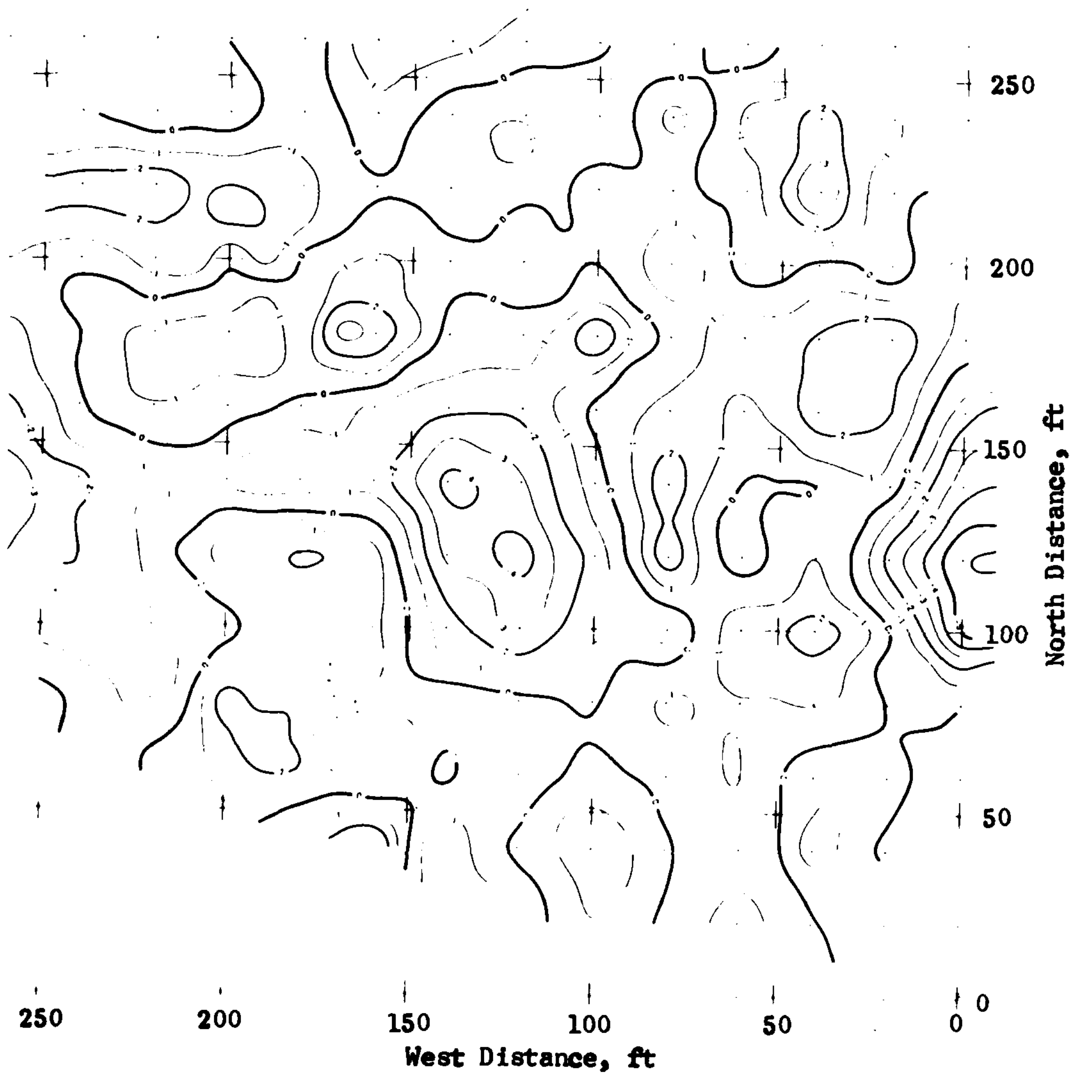

Figure 27. Elkins residual map, second derivative, 20-ft spacing data

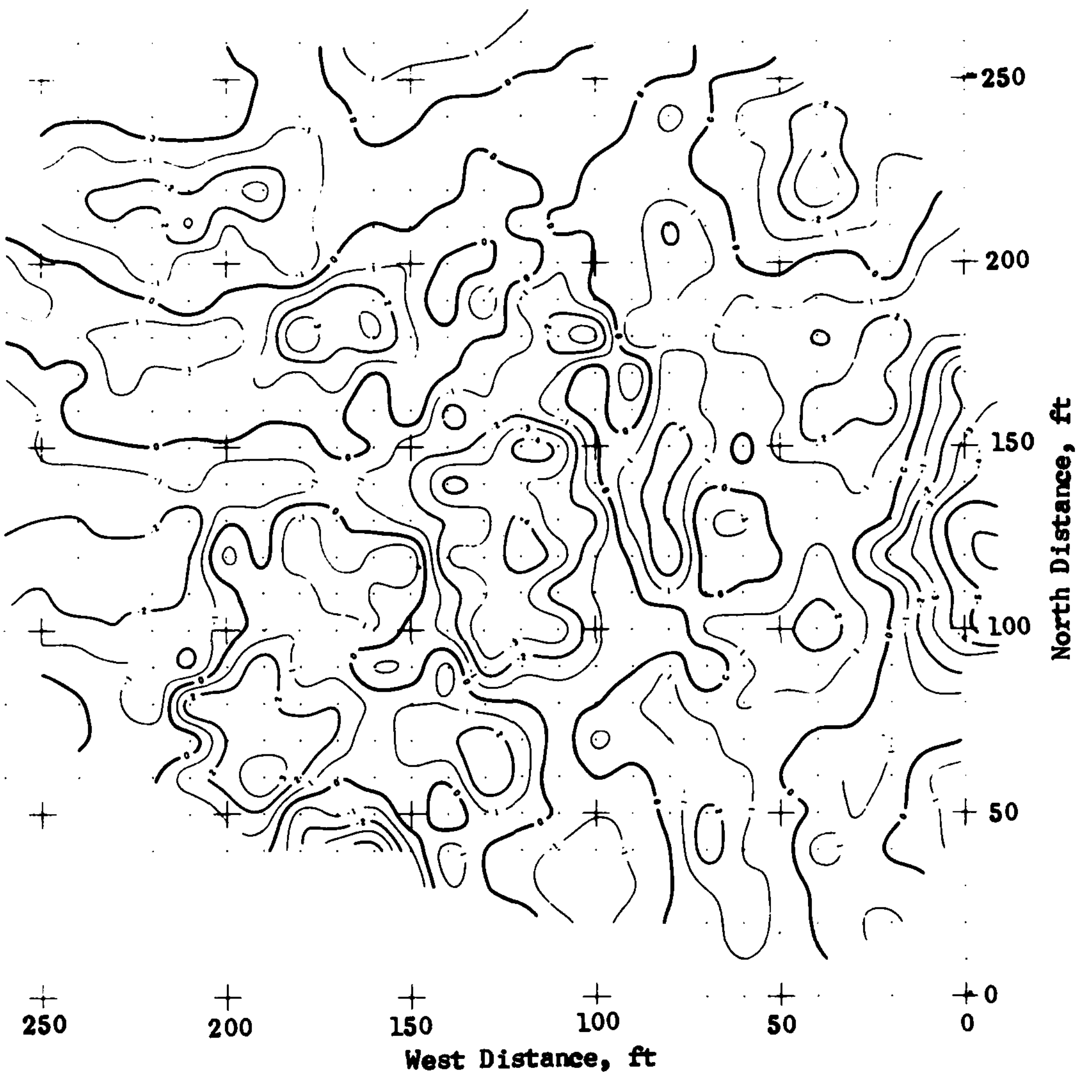

Figure 28. Elkins residual map, second derivative, 10-ft spacing data

$$g_z'(0) \simeq g_o(0) - 0.72\ \bar{g}_1(a) - 0.28\ \bar{g}_5(3a)$$

where again a is taken as 20 ft. This transformation is applied without the smoothing inherent in the formula for $g_z''(0)$. Thus, in principle, the transformed maps should have greater anomaly resolution than residual gravity anomaly maps. Figures 29 and 30 are the transformed first derivative maps for 20-ft and 10-ft data grids, respectively. The contour values should be considered in a relative sense with arbitrary units.* Again there is great similarity between the residual maps (Figures 23 and 24) and the first derivative maps with regard to anomaly location and orientation; the first derivative maps seem to exhibit greater anomaly resolution, however, as expected. All of the anomaly features identified on the residual maps can be seen on the first derivative maps. Some of the anomalies such as B and C which appear with a single anomaly center in Figures 23 and 24 are resolved into two anomaly centers in Figures 29 and 30.

46. The similarity between the residual and first and second derivative maps can be emphasized by examining selected profiles. Figures 31 and 32 compare g_z, g_z', and g_z'' from Figures 24, 28, and 30, respectively, for the 0 and 80 N-S profile lines.

47. The smoothing effect caused by the particular second derivative transformation which was used is illustrated very well in Figure 32 for the 80 N-S line. Figure 31 illustrates to some extent the greater resolving power of the first derivative; the large negative anomaly feature is seen to have a multistructure origin in the g_z' profile; whereas, such an origin is only suggested in the g_z profile.

Quantitative interpretation

48. It is possible to calculate uniquely the gravity anomaly on the surface due to a subsurface structure. Information needed for this calculation includes structure geometry, size, depth, and density

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* Strictly speaking, first derivative units, the Eötvos (E), where 1E = 0.1 μGal/m, can be obtained by multiplying the contour values by 18.31365.

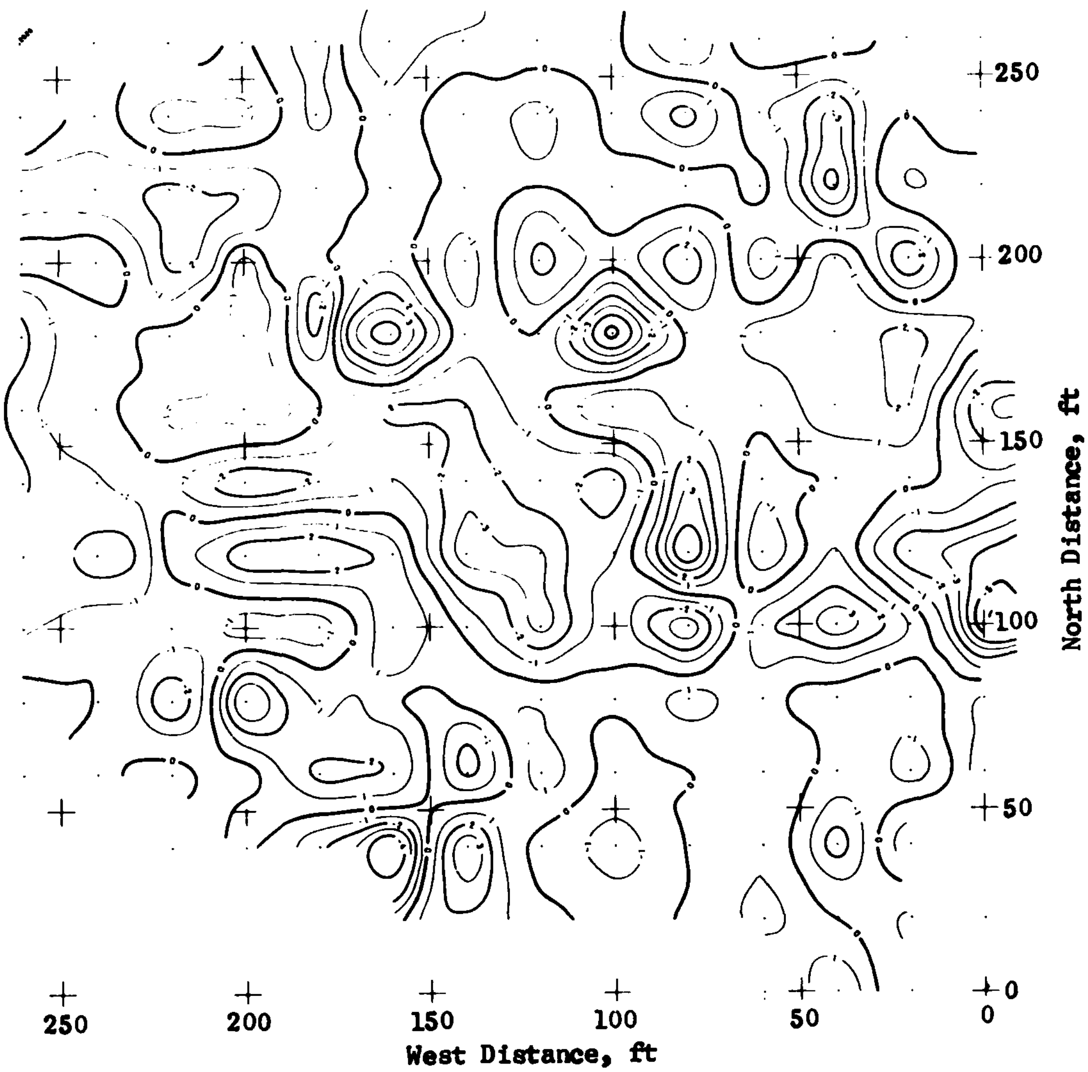


Figure 29. First derivative map, 20-ft spacing data

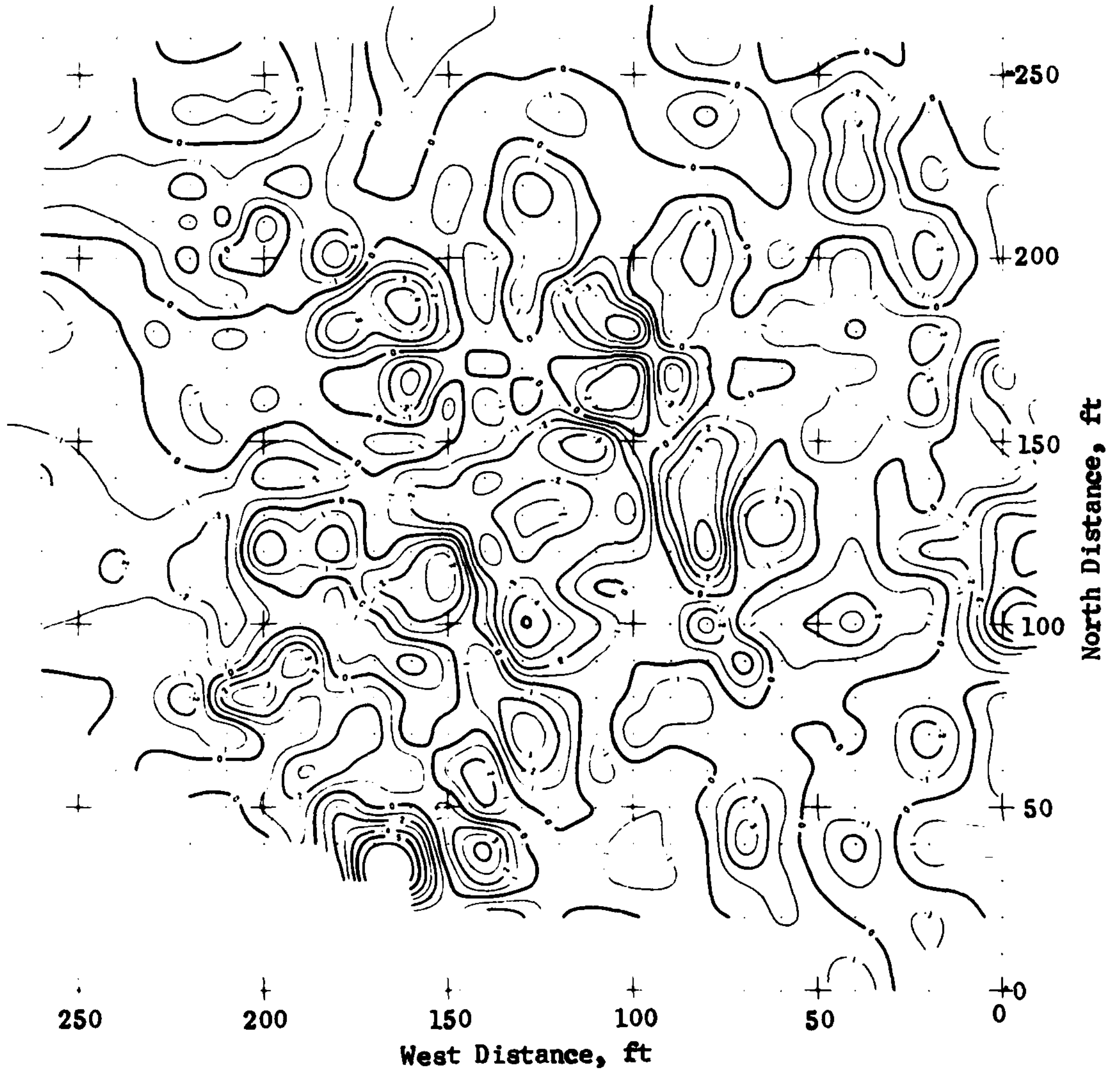


Figure 30. First derivative map, 10-ft spacing data

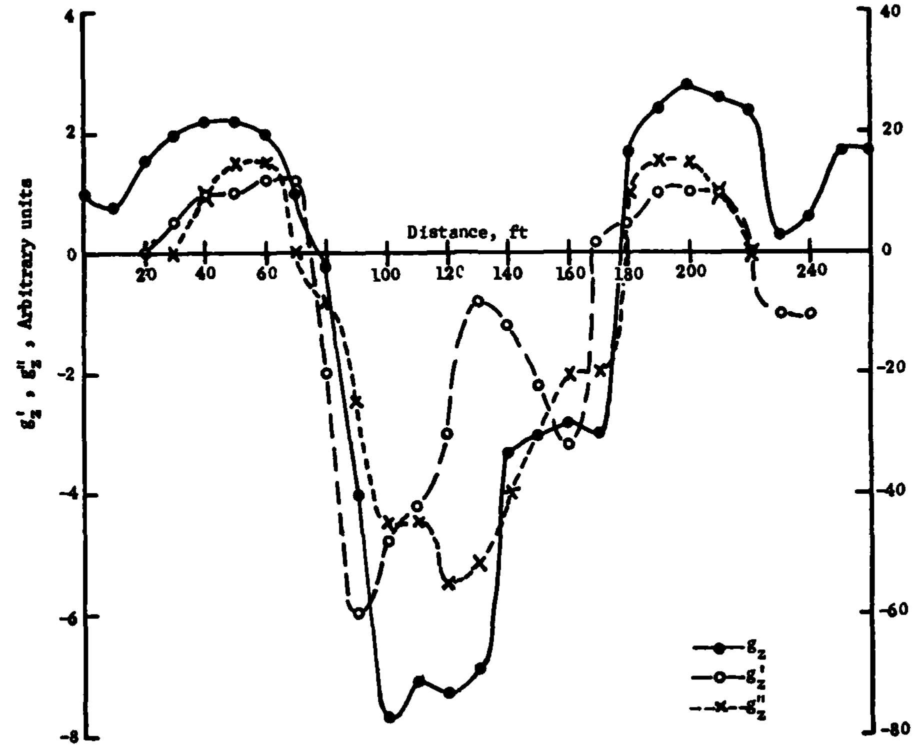


Figure 31. Comparison of residual gravity (g_z), first derivative (g_z'), and second derivative (g_z'') profiles along the 0 N-S line

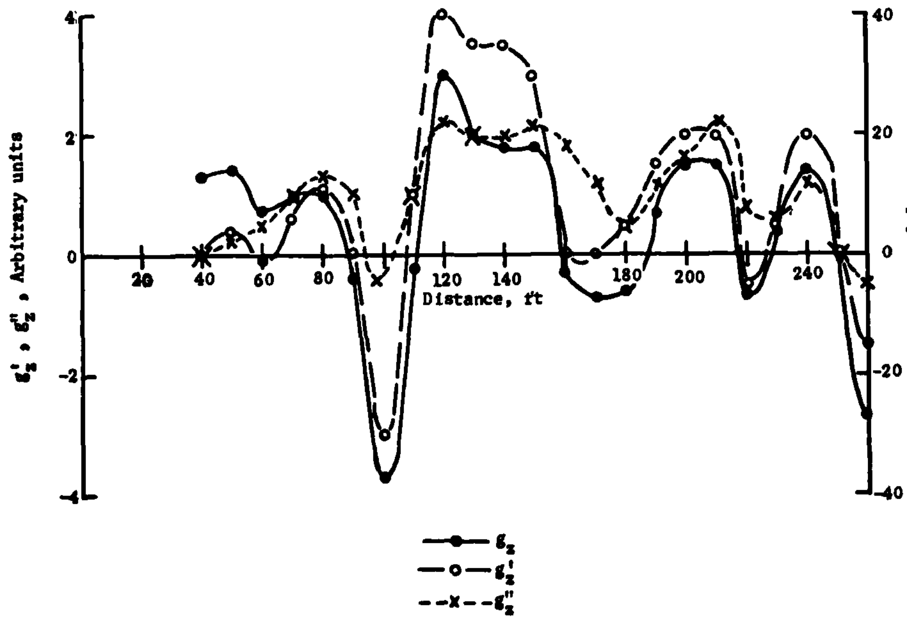


Figure 32. Comparison of residual gravity (g_z), first derivative (g_z'), and second derivative (g_z'') along the 80 N-S line

contrast. The inverse problem involves trying to calculate or deduce this information about a structure from the measured gravity anomaly on the surface, and this problem is inherently nonunique; i.e., there are many possible solutions. However, for a given site, a basic knowledge of the geology in the area can significantly reduce the number of possibilities. Thus, in karst regions, localized negative anomalies are likely due to solution features such as described in Part II.

49. As an example of solution of the inverse gravity problem, consider anomaly B in Figure 23. The anomaly is caused by a three-dimensional structure, and since the contours are fairly symmetric about the center, the structure is likely symmetric. The simplest possible three-dimensional symmetric structure model is a sphere. Consider a spherical model of radius R, depth to center z_o, and density contrast $\Delta\rho$. The gravity anomaly profile on the surface over the center of the model is expressed by (Butler 1980)

$$g_z = \frac{4}{3}\pi R^3 \Delta\rho\gamma \frac{z_o}{(x^2 + z_o^2)^{3/2}} = \Delta M\gamma \frac{z_o}{(x^2 + z_o^2)^{3/2}}$$

where $\gamma = 6.67 \times 10^{-11}\ m^3/kg\text{-}sec^2$, ΔM symbolizes the mass anomaly of the model, and x is the surface position ($x = 0$ is directly above the center of the model). From this equation, the depth is given by

$$z_o = 1.305X_{1/2}$$

where $X_{1/2}$ is the half-width of the profile at its half-maximum value points. Knowing z_o, the mass anomaly can be calculated from the value of the profile at $x = 0$, $g_z(0)$, using the following relation

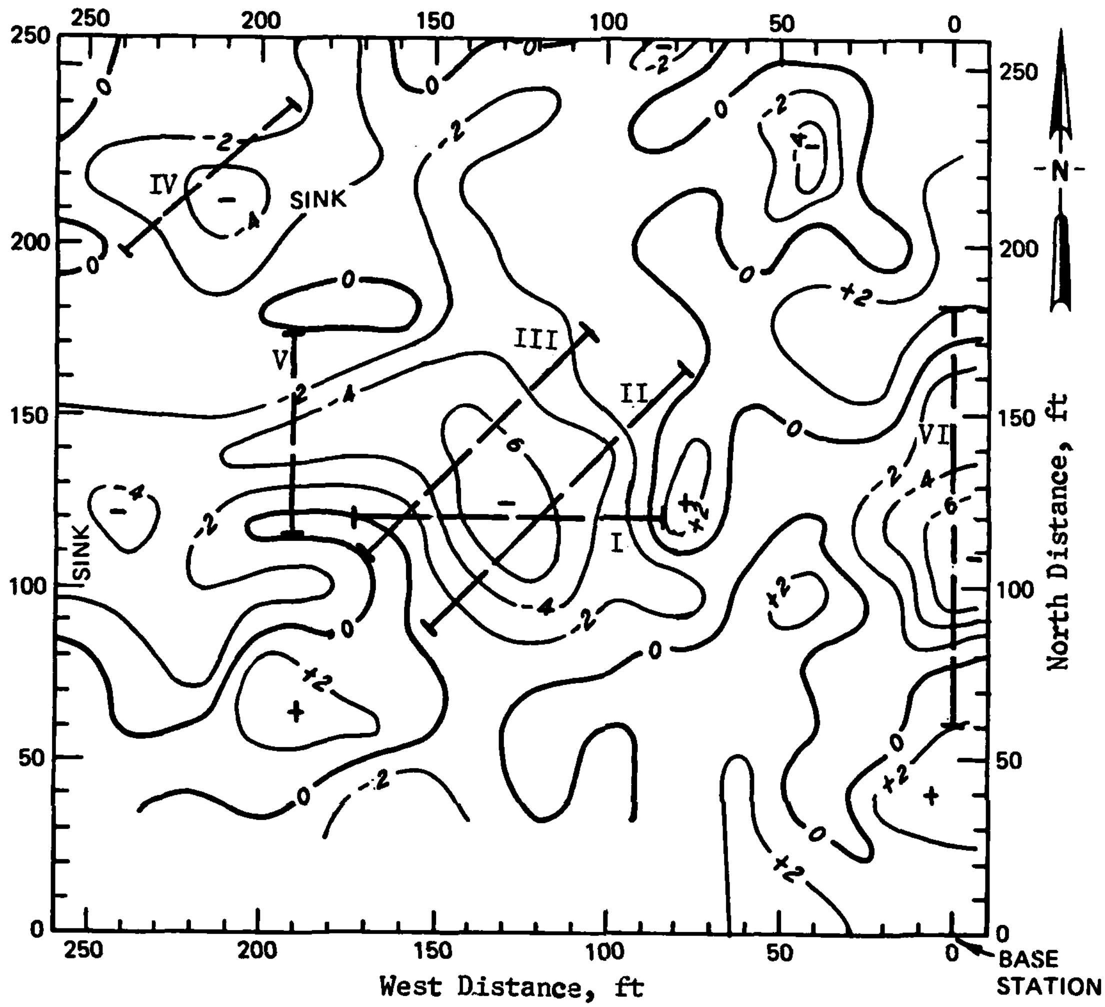
$$\Delta M = \frac{g_z(0)\ z_o^2}{\gamma}$$

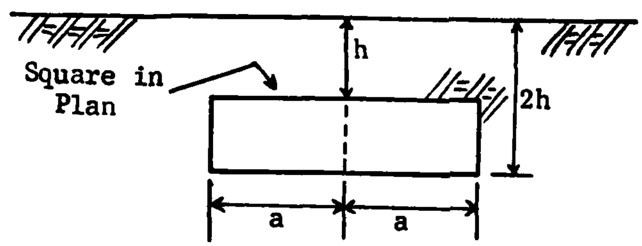
Finally, knowing ΔM , if the density contrast is known or can be estimated, the radius can be calculated, or vice versa.

50. For anomaly B, $X_{1/2}$ varies from 10 ft (3.0 m) to 16 ft (4.9 m), depending on the orientation of the profile taken across the anomaly. Thus, the predicted depth to the center of the structure lies in the range of $13 \leq z_o \leq 21$ ft (4 to 6.4 m) based on the assumption of a spherical geometry. Based on $g_z(0) = -41$ μGal and assuming $\Delta\rho = -2.0$ g/cm^3 (for an air-filled cavity), the radius is seen to be in the range $7.4 \leq R \leq 10.1$ ft (2.3 to 3.1 m). Since the sphere is the most compact three-dimensional model, depths calculated using this model will tend to err on the high side, since less compact structures must be located at shallower depths to produce the same anomaly. The confirmatory boring placed at (225,40) to investigate this anomaly (see Appendix B) revealed that the gravity anomaly is due to both a thicker than normal soil profile (representing a distributed mass anomaly) and a partially clay-filled cavity centered at about 13 ft (4.0 m).

51. For other models, it is possible to calculate gravity anomalies for a range of sizes, depths, and density contrasts and, thus, prepare a catalog of profiles for comparison with measured field gravity profiles. The basic procedure is to plot the profile data on transparent log-log paper and then overlay the plotted data on the set of standard curves for the chosen class of models. The measured profile is matched with a standard profile, and the required model parameters are determined from axis intercepts in a manner analogous to the use of the familiar resistivity master curves for layered earth models.

52. Professor Robert Neumann selected six profiles across anomalies A, C, and D for quantitative interpretations (Neumann 1979); these profile lines are shown in Figure 33. The class of models chosen for all the interpretations are square in plan and rectangular in cross section, with thickness equal to the depth to the top. This class of models was chosen after comparing the character of the measured profiles with several different classes of models of a similar nature. The following tabulation summarizes the results of the quantitative interpretations performed by Professor Neumann:





Model Used for Quantitative Interpretations

Figure 33. Location of six gravity profiles selected for quantitative interpretation

Profile No.	Depth to Top h, ft	Depth to Bottom H, ft	Width/Length 2a, ft	Density Contrast $\Delta\rho$, g/cm^3
I	12.2	34.4	33.6	-1.72
II	15.1	30.2	30.2	-1.68
III	14.8	29.6	29.6	-1.66
IV	8.9	17.8	34.2	-1.05
V	12.8	25.6	19.8	-1.85
VI	16.8	33.6	46.8	-1.62

These results are compared to known cavity dimensions and the results of exploratory borings in Part V.

Summary

53. Results of a microgravity survey consisting of 420 gravity stations are presented in this section. Use of the known conditions at the site was made in planning the survey, i.e., a denser grid of gravity stations was used over the known cavity system at the site in order to assess the role of grid spacing in allowing delineation of the cavity system. Two methods of interpreting the data are presented--qualitative and quantitative. Both methods are based solely on the gravity data, and only passing reference is made to known conditions at the site and results of the confirmatory drilling program.

54. Qualitative interpretation of the data relies on examination of residual gravity contour maps or processed gravity derivative maps to pick anomalous areas at the site, where negative gravity anomaly features may be indicative of clay pockets, cavities or other solution features (such as zones where extensive solutioning has occurred but without "large" cavity development) which should be investigated by confirmatory drilling. The method of quantitative interpretation used in this report relies on choosing representative profile lines across closed gravity anomaly features. Then by assuming a model of the feature causing the gravity anomaly, the size, depth, and density contrast are deduced by comparing the measured profile with standard profiles for

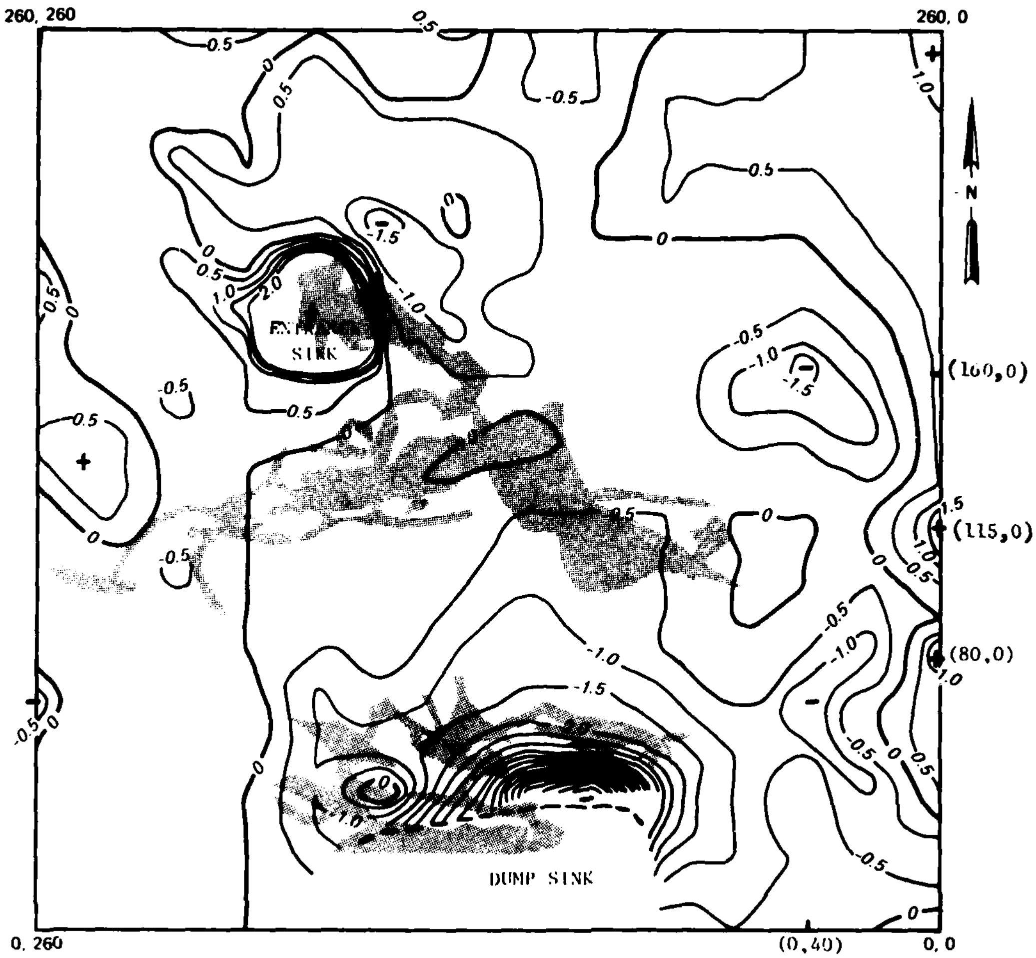
the assumed model. Comparison of the qualitative and quantitative interpretations with the known cavity system, results of the drilling program, and results of the magnetic survey are discussed in Part V of this report.

PART V: GEOPHYSICAL-GEOLOGICAL CORRELATIONS

Correlation of Geophysical Results and the Known Cavity System

55. The most obvious way to evaluate the microgravimetric and magnetic survey results is to compare the residual anomaly contour maps with the known cavity map. Essentially, the cavity map in Figure 5 is correct with regard to the sizes and relative layout of features. Boreholes which penetrated the system verified the mapped depths in two places. A limited number of compass checks during entry into the cave system confirmed that the map orientation of the Big Room may be off by as much as 10 deg (should be rotated clockwise) although the point of rotation was not determined. Also the actual location of the Secondary Entrance is at (110,260) or about 10 ft northwest of its mapped location. The Dump Sink is enlarging with time and is somewhat larger than shown in Figure 6, with the northern rim approximately parallel to the 35 E-W line. The bottom of the Dump Sink slumped by about 6 ft sometime during the period 15 January to 15 April 1980. With these minor reservations, the cavity map of Figure 6 may be used for correlation with the geophysical results. It was anticipated from the beginning, however, that there were solution features at the site not shown on the cavity map.

56. The general correlation of the residual magnetic anomaly map with known features at the sites was discussed in Part II. Figure 34 shows the cavity and magnetic maps superimposed for completeness. As discussed earlier, the only significant correlations occur at the Primary Entrance, where the iron ladder produced a large magnetic high, and near the Dump Sink, where a large magnetic low occurs. The magnetic low near the Dump Sink is located above the small secondary cavity system which can be entered through openings in the sink, although the low anomaly extends considerably north and east of the known cavity system. Since the shallowest mapped depth to the secondary cavity system is about 15 ft, it is difficult to explain the magnetic low on the basis of the cavity system. One possibility is that the anomaly is a flanking

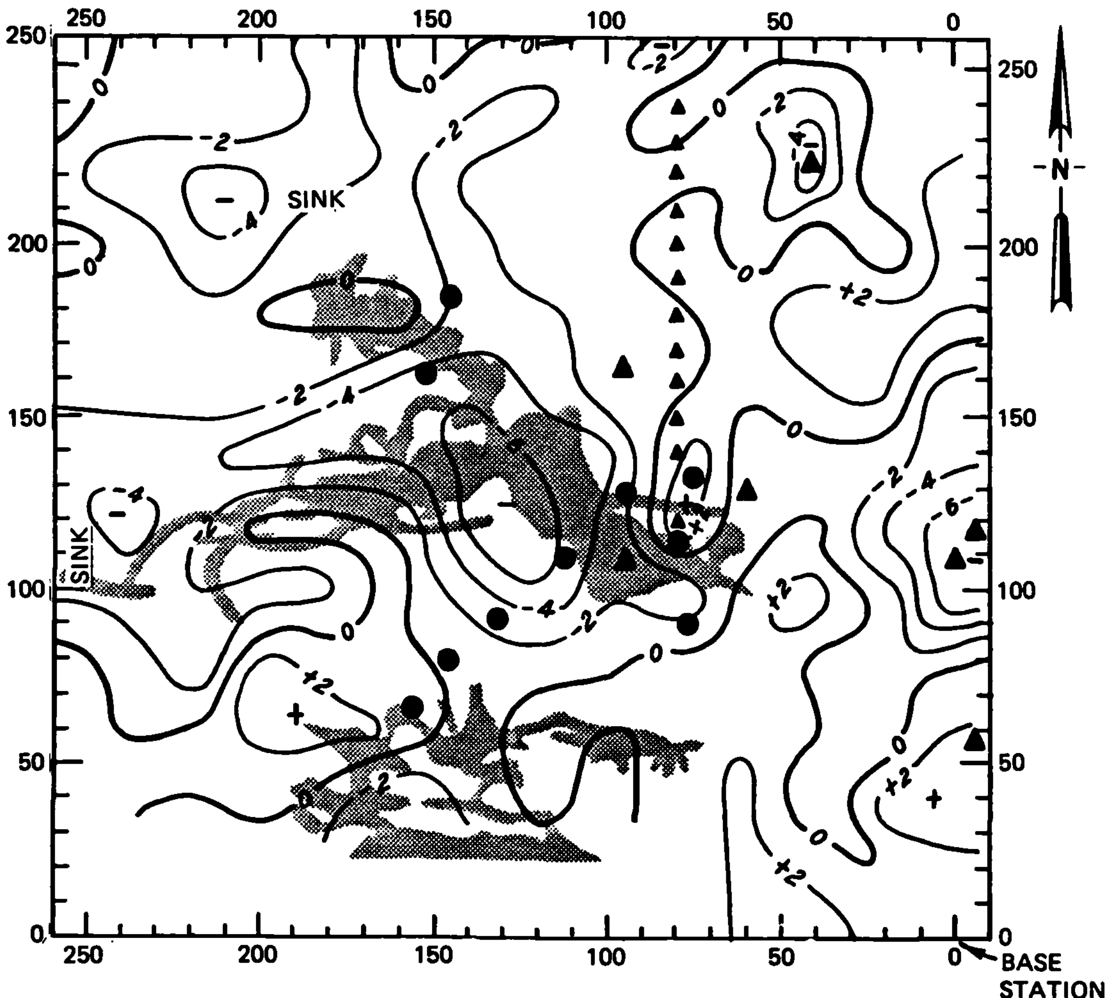


NOTE CONTOUR INTERVAL 50γ

Figure 34. Magnetic survey contour map with cavity map superimposed

low caused by metallic material in the sink, although the size and shape of the anomaly makes this seem unlikely.

57. Figures 35 and 36 present the residual gravity anomaly contour maps of Figures 23 and 24, respectively, with the cavity map superimposed. The overall correlation of the negative gravity anomalies with the mapped cavity system is excellent. Both the location and directional trends of anomaly A (see Figures 23 and 24) correlate very well with the main cavity system. The gravity contours would match the cavity map even better if either were rotated about 10 deg (clockwise for the cavity map and counterclockwise for the gravity anomaly contour),



● TEST BORING
▲ EXPLORATORY BORING
▲ CONFIRMATORY BORING
− NEGATIVE GRAVITY ANOMALY REGION
+ POSITIVE GRAVITY ANOMALY REGION

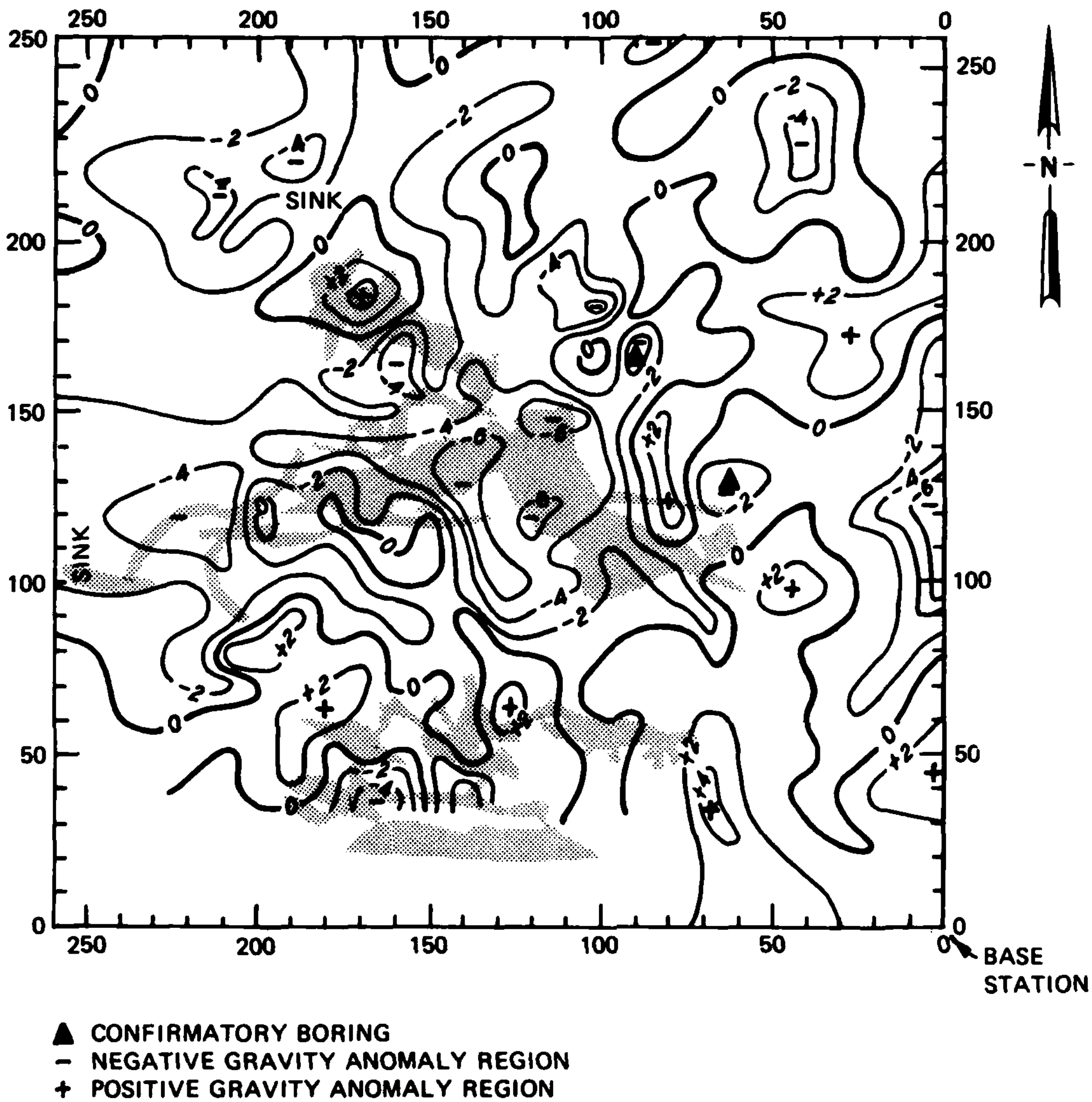
CAVE

NOTE: CONTOUR INTERVAL = 0.02 mGAL (20 μGAL)
STATION SPACING = 20 FT

SCALE

0 FT 50

Figure 35. Superposition of 20-ft spacing residual gravity anomaly and cavity maps



NOTE: CONTOUR INTERVAL = 0.02 mGAL (20 μGAL)
STATION SPACING = 10 FT

Figure 36. Superposition of 10-ft spacing residual gravity anomaly and cavity maps

which is consistent with crude angle measurements made in the cavity system. Note the occurrence of a gravity high over the Primary Entrance/Sink. If elevations were known accurately enough within the sink and opening, the gravity corrections should just compensate and result in a zero anomaly due to the Primary Entrance/Sink. However, the elevations and actual geometry of the opening were poorly defined, and gravity data within the sink area were sparse. The Primary Entrance/Sink seems to be expressed properly in Figure 35, but a positive anomaly occurs in Figure 36 which extends over a portion of the Entrance Room. Also, very near the surface in the area above the Entrance Room, the basal limestone member of the Hawthorne Formation occurs, which has a density contrast of about +0.2 g/cm^3 with the underlying limestone, and may contribute to the positive gravity anomaly.

58. Both Figures 35 and 36 indicate negative anomalies over the small secondary cavity system near the Dump Sink. Also, both figures indicate extension of the negative anomalies to the north joining the negative anomaly region over the main cavity system. This further suggests that the two cavity systems may be connected. Although portions of the secondary cavity system are too deep (30 to 35 ft) or too small (approximately 2 to 4 ft in vertical dimension) to be delineated very well by gravity (see Figure 16 and Butler 1980), the distribution of positive and negative areas correlates very well with the mapped cavity features.

59. Very small features of the cavity system are not delineated by the gravity maps, such as the small finger projection from the Big Room or the individual features of the west-southwest extension of the main cavity system. These features are too deep and too close together to be resolved by the gravity maps. Further processing, such as subtracting a local regional field from Figure 36, defined say from Figure 35, might improve the resolution, but this has not been attempted. The results are already adequate for zoning the site for most purposes without further processing of the data.

Geophysical and Geological Correlations along Profile Lines

Concepts

60. Basically the function of geophysical surveys in a site investigation program is to assist in determining subsurface conditions at a site. This function involves hypothesizing structural features consistent with the known geological conditions which could explain particular geophysical results. For site investigations in karst regions, primary "targets" of geophysical surveys are anomalous zones which can be ascribed to solution features. Thus, the geophysical survey results are called on to locate anomalous zones in plan, estimate size and depth, and assess the nature of the feature (i.e., clay pocket, grike, solution-widened joint or fracture, rock surface pinnacle, air-filled cavity, clay-filled cavity, etc.). While this can be done possibly from the results of a single geophysical method, the preferable procedure is to rely on complementary geophysical results* to give added confidence to the interpretation. Of course, drilling or direct investigation of anomalies is required in the end, but the combination of geological and geophysical work can often significantly reduce the amount of drilling required to achieve adequate definition of subsurface conditions at a given site.

61. The correlation of complementary geophysical results can be used to restrict the possibilities when assessing the nature of the feature causing geophysical anomalies. Listed in the table below are qualitative indications of the nature of gravity, resistivity, and magnetic anomalies expected to be associated with various solution features. (The terms "high" and "low" are used in a completely relative manner.)

Feature	Gravity	Resistivity	Magnetic
Clay pocket or grike (at the top of rock), clay-filled sink	Low	Low	High

(Continued)

* Complementary geophysical methods measure or respond to different physical parameters of the soil/rock medium.

Feature	Gravity	Resistivity	Magnetic
Air-filled cavity	Low	High	None (?)
Clay-filled cavity	Low	Low	High (?)
Limestone pinnacle	High	High	None(?) or relative low if surrounded by clay

These concepts are illustrated in the following examples of gravity, resistivity, and magnetic profiles along N-S lines at the Medford site. The resistivity program and results at the Medford site will be discussed in detail in other reports (e.g., Butler et al. 1982). Briefly, the resistivity results presented in the following examples are from horizontal profiling surveys using a Wenner array with an electrode spacing of 40 ft and measurements every 10 ft along the line; with this electrode spacing, the depth of investigation is at least 30 ft.

0 N-S line

62. The easternmost boundary of the surveyed area at the site, the 0 N-S line, was used as a common profile line for all the surface geophysical methods used at the site. Prior to the geophysical surveys and the drilling program, nothing was known about the subsurface beneath this profile line. Gravity, resistivity, and magnetic profiles along this line are presented in Figure 37. The outstanding feature in Figure 37 is a broad gravity low reaching nearly -80 μGal in the region 100 to 130 ft of the profile line and increasing to -30 μGal in the region 130 to 180 ft (anomaly C). An apparent resistivity of about 400 ohm-ft appears to be the "normal" value for the site (for the Wenner array with A = 40 ft) away from the known cavity system. Compared to this normal value, the resistivity profile exhibits a broad, low amplitude high across the region of the gravity low, with a secondary peak in the profile occurring at the location where the gravity low changes from -80 μGal to -30 μGal. The magnetic profile exhibits a high from 100 to 130, which has an apparent profile width considerably shorter than that for the gravity and resistivity anomalies. The gravity low and resistivity high suggest an air-filled cavity or cavities, while the magnetic high suggests the possible presence of clay, although due to the short spatial width of the magnetic anomaly, the clay may be shallower and not

PROFILE LINES – O W

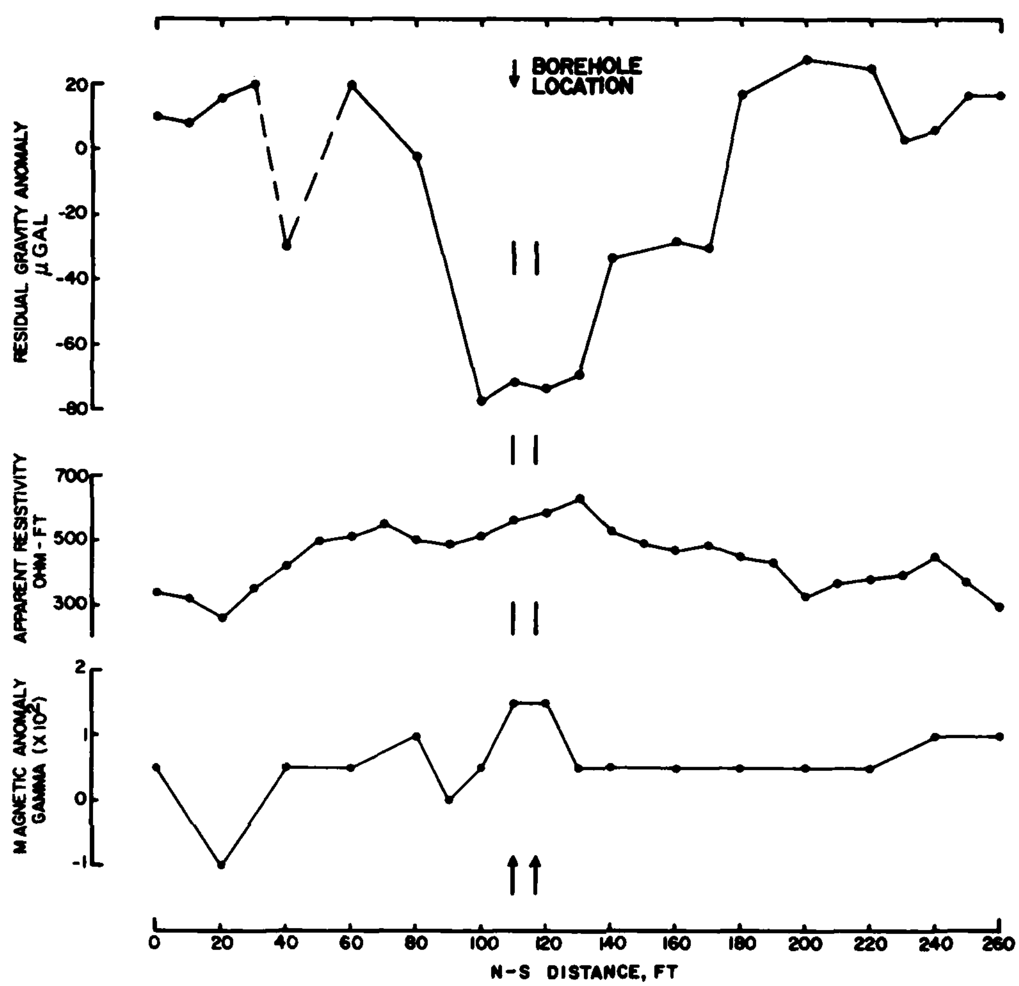


Figure 37. Gravity, resistivity, and magnetic profiles along the 0 N-S line

associated with the cavity as a filling material. This region of the profile line was also interpreted as anomalous based on results of other geophysical surveys (seismic refraction, surface radar, resistivity sounding, and pole-dipole resistivity).

63. Two borings were placed to investigate the cause of the anomalous geophysical results, as shown in Figure 37. The borings (E20 and E19) were located at (110,0) and (117,-5) (slightly east of profile line). Boring logs from these two boreholes are shown in Figure 38. Boring E20 encountered two air-filled cavity zones each about 2 ft thick

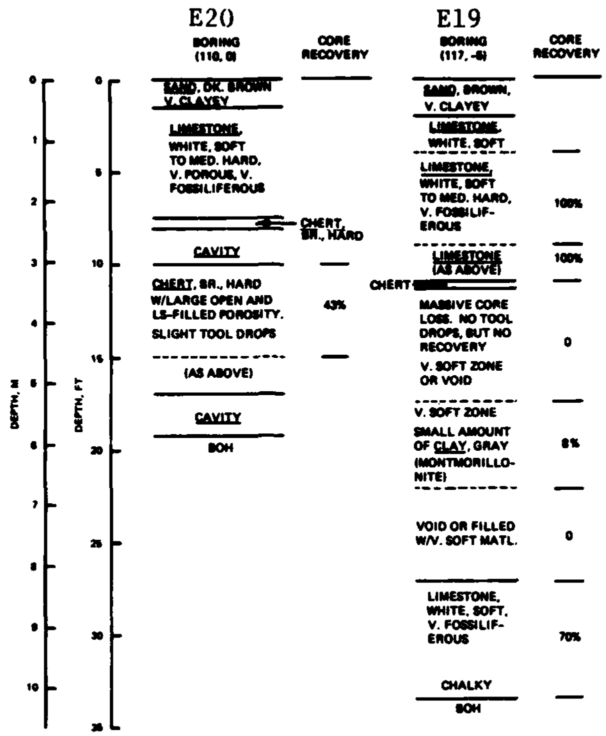


Figure 38. Boring logs for borings E19 and E20

at depths of 8 and 17 ft. The two cavities were separated by about 5 ft of chert with very large (1- to 2-in. diameter) air- and limestone-filled porosities and several small air-filled cavity zones. Boring E19 encountered a zone at about 12 ft and extending to 27 ft which is apparently a cavity that is partially or entirely clay-filled. No air-filled cavities, as evidenced by drill tool drops, were encountered in E19. Thus the gravity and resistivity anomalies are caused by a cavity feature which apparently becomes deeper and clay-filled to the east of the profile line. The magnetic anomaly is due either to the apparently very clay-rich soil at the location or to the anomaly produced by the clay-filled section of the cavity to the east.

64. The results of a quantitative interpretation of a gravity profile line across this anomaly is presented in Part IV as profile VI in the tabulation in paragraph 52. Comparing the interpreted depths to the boring log in Figure 38, the predicted depth to top of the cavity is too large by a factor of 2 for the condition found in boring E20 and by

a factor of 1.4 for the conditions in boring E19. The difficulty in interpreting this anomaly is due to the complex nature of the anomaly; i.e., it is difficult to fit the complexly shaped gravity profile, likely due to two separate solution features or a complexly shaped single feature, to the regularly shaped profile for the chosen model. The interpreted density contrast ($-1.62\ g/cm^3$) is fairly realistic for the conditions shown for boring E20.

40 N-S line

65. The 40 N-S line again is in an area of the site where subsurface conditions were unknown prior to the field investigations. Geophysical survey profiles along this line are given in Figure 39. All of the profiles exhibit considerable variability, and as will be seen in the following discussion on the 80 N-S line, much of the variability is likely due to irregularities in the top of the limestone (i.e., limestone pinnacles and clay pockets). A gravity low with magnitude of -40 μGal at (220,40) occurs over the region 210 to 260 of the profile line (anomaly B). A resistivity low and an apparent relative magnetic high are associated with the gravity low, although the magnetic high, if real, is certainly not well defined. These geophysical anomalies suggest a clay-filled cavity or a clay pocket. Boring E18 was placed at location (225,40) on the line to investigate the cause of the geophysical anomalies; Figure 40 presents the boring log. A partially clay-filled cavity was encountered at a depth of 9 ft, extending to 14.5 ft. Also, sand was encountered to a depth of 6.5 ft, considerably thicker than typical for the site, suggesting a shallow sand-filled pocket or grike in the top of the limestone. Thus, the geophysical anomalies, in particular the gravity low, are due to both the shallow sand-filled feature and the somewhat deeper partially clay-filled cavity. It is the contribution to the gravity anomaly from the shallow sand-filled feature, which is possibly large in areal extent, which resulted in too large a predicted depth for the simple quantitative interpretation attempted in Part IV.

60 N-S line

66. The 60 N-S line crosses a small, closed-gravity anomaly

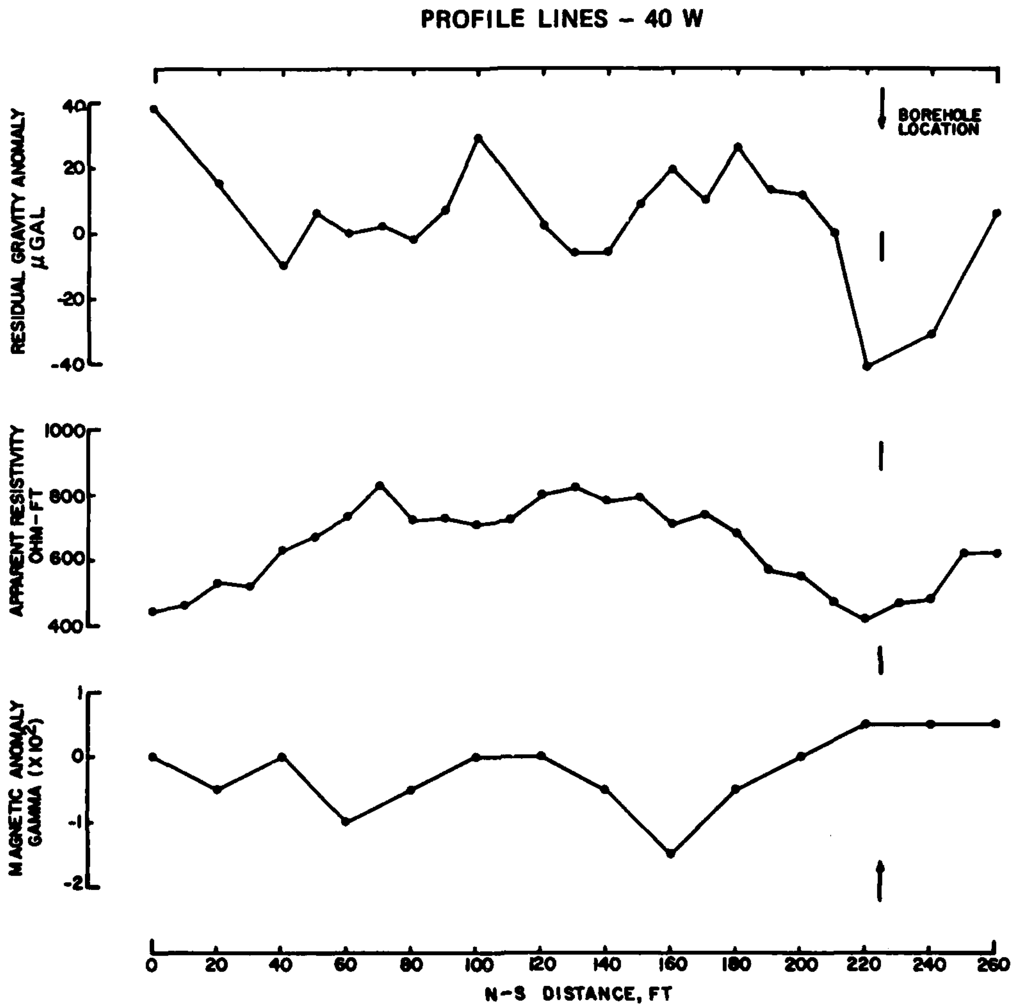


Figure 39. Gravity, resistivity, and magnetic profiles along the 40 N-S line

E18

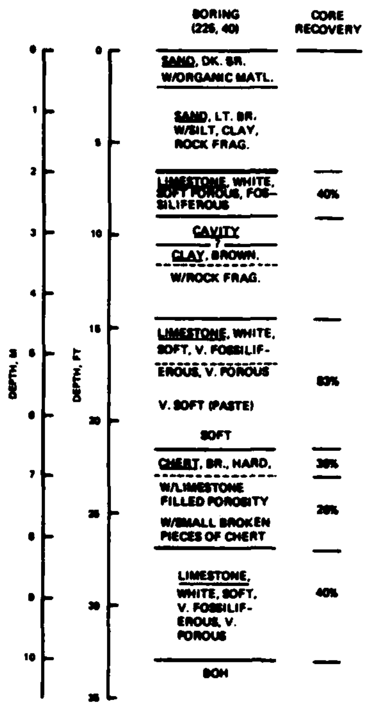


Figure 40. Boring log for boring E18

(anomaly E) which only appeared on a contour map of the 10-ft station spacing data. Also, this line just crosses the easternmost extension of the mapped cavity system. The geophysical profiles shown in Figure 41 again have the variability typical of an irregular limestone surface. Boring E23 was placed to investigate the cause of the small gravity anomaly (-30 μGal) at (130,60). A broad resistivity high occurs over the central portion of the profile line. Two factors likely account for this resistivity high: (a) a broad region of increased porosity due to solution, and (b) the close proximity of the large known cavity system. Significantly, there is a relative resistivity low superimposed on the broad high which is symmetric about the location of the gravity low. There appears to be a relative magnetic high to the south and a low to the north of the centers of the gravity and resistivity anomalies, although it is clear that probably in the absence of the other anomalies,

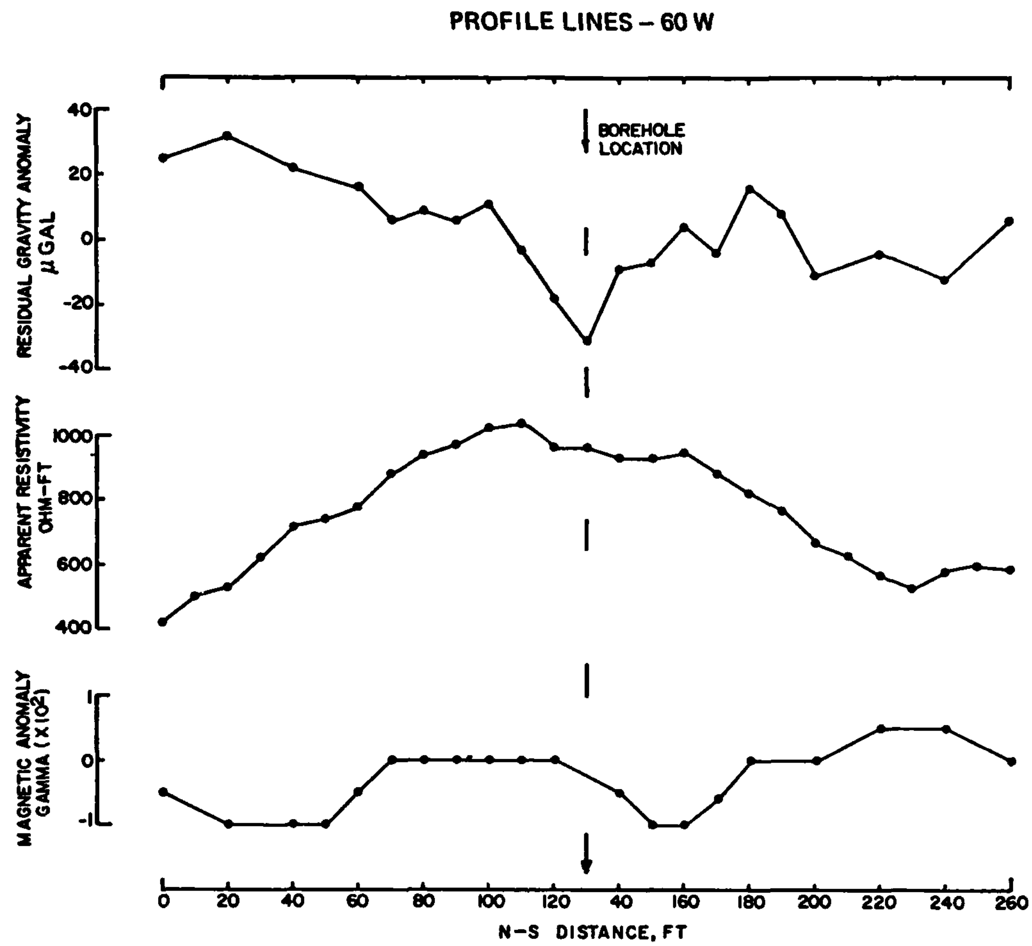


Figure 41. Gravity, resistivity, and magnetic profiles for 60 N-S line

no significance would have been attached to this magnetic signature. These geophysical anomalies suggest a clay-filled cavity or pocket. Boring E23 (Figure 42) encountered a clay-filled cavity with bottom at 18 ft. The top of the cavity is either at 9 or 14 ft, with the exact nature of the material between 9 and 14 ft uncertain as indicated in the boring log. While the simple quantitative interpretation attempted for the gravity anomaly on the 40 N-S line failed to some extent due to the multiple solution features, the same procedure would work quite well for the present case.

<u>80 N-S line</u>

67. The 80 N-S line was the most extensively investigated profile

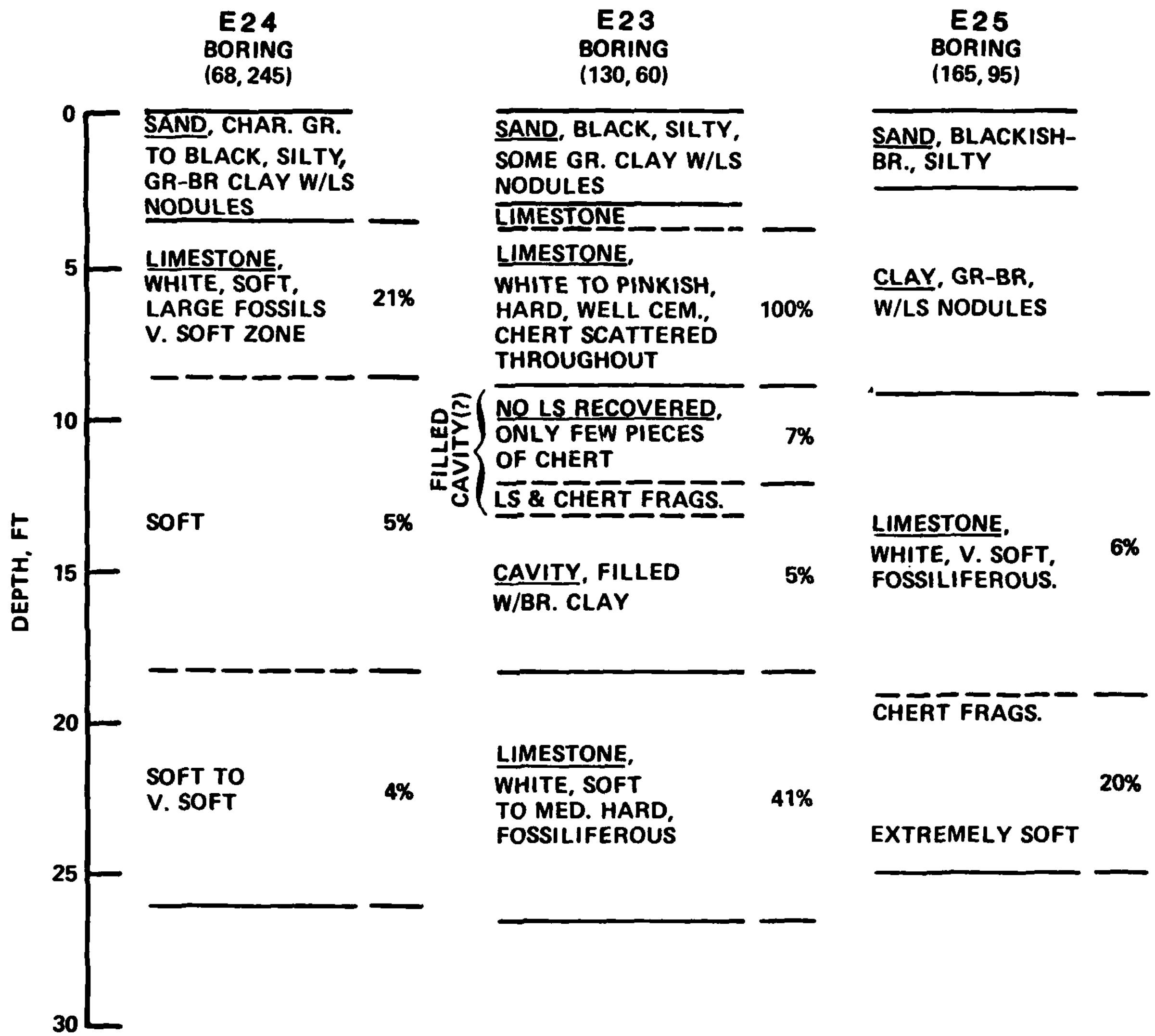


Figure 42. Boring logs for borings E23, E24, and E25

line at the Medford site. A geologic profile along this line is presented in Figure 14. For the 0, 40, and 60 N-S lines, only the most significant geophysical anomalies were selected for verification drilling and discussion. For the 80 N-S line, however, even small and subtle features of the geophysical profiles can be correlated to known geological conditions. Figure 43 presents the gravity, resistivity, and magnetic profiles along this line. Each profile is shown above the geologic cross section for easy comparison. Two different resistivity profiles (Wenner arrays with A = 10 ft and A = 40 ft) are shown in Figure 43. Two small features of the known cavity system cross under this line as shown in the geologic cross section. Since the cavity features are air-filled, the corresponding geophysical profiles should show a gravity low and a resistivity high for A = 40 ft, but the resistivity profile for A = 10 ft and the magnetic profile should show no effect due to the cavities. The geophysical results are entirely consistent with this. The center of the large resistivity high is shifted to the north due to the proximity of the Big Room of the cave system to the northwest.

68. For the northern half of the line, note the excellent correlation between the gravity and geologic profiles (Figure 43): gravity lows over clay pockets and gravity highs over limestone pinnacles. The small variations in the gravity profile from positions 40 to 80 ft on the line may likewise be due to small undulations in the top of the limestone. The resistivity profiles in Figure 43 illustrate how two electrode spacings can be used in horizontal profiling to give information of depths of features causing anomalies. For example, both profiles exhibit relative lows centered at about 180 ft on the line above a clay pocket. Because the profile for the 10-ft electrode spacing shows the anomaly, the causative feature must be shallow. Small fluctuations in the A = 10 ft profile correlate with the remaining clay pockets and the limestone pinnacles. The second clay pocket and limestone pinnacle located near the 200- to 240-ft positions are not resolved on the A = 40 ft profile due to the large volume of material influencing the measurements. A large clay pocket at 260 ft is seen to significantly affect the A = 40 ft profile.

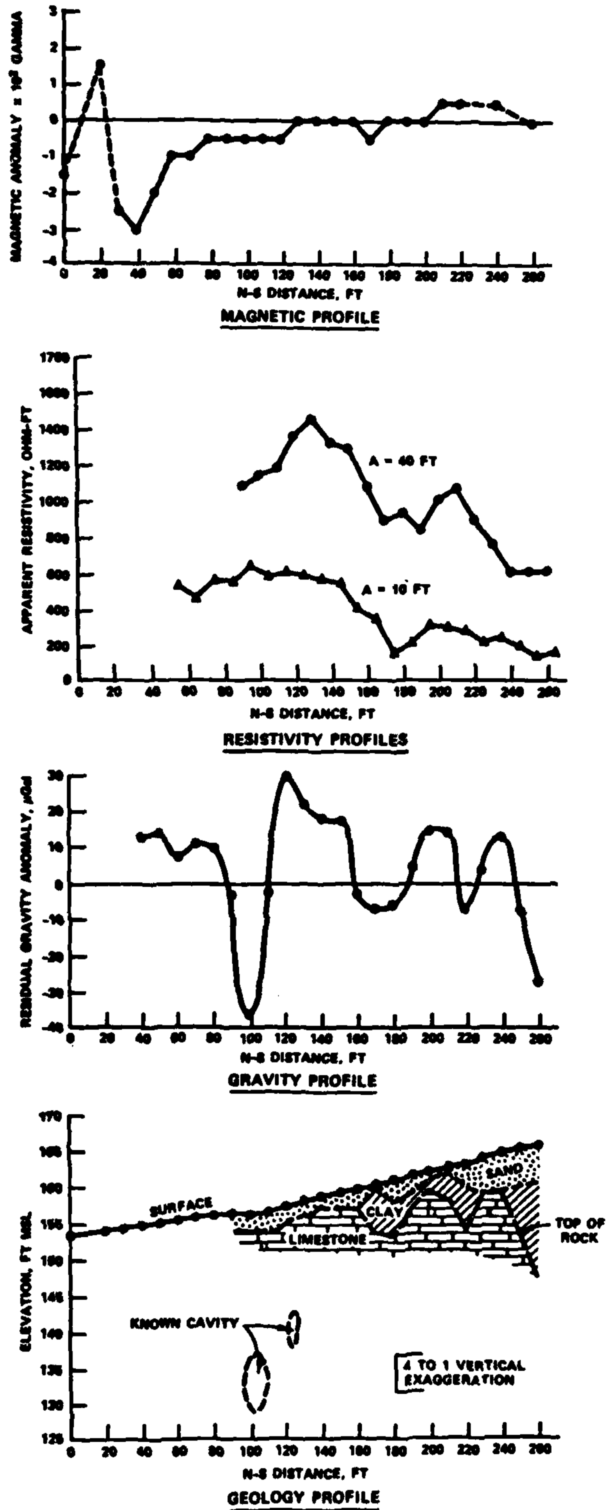


Figure 43. Geophysical profiles and geologic cross section along the 80 N-S line

69. Although the magnetic profile (Figure 43) exhibits a relative shift to higher values from south to north along the line as would be predicted due to the presence of the clay, the profile has no identifiable pattern which defines the clay pockets. It is possible that the clay pockets in this case are so close together that the offset positive-negative anomalies expected superimpose in such a way as to mask the pattern. The south end of the profile exhibits a relative positive-negative pair which is possibly due to the metal present in the Dump Sink.

70. The residual anomaly contours in Figure 36 suggest that the clay pocket centered at about (170,80) (Figure 43) may extend westward toward the area of the main cavity system. Boring E25, placed to investigate a small, closed, negative anomaly feature at (165,95) that appeared when the 10-ft spacing data were contoured, encountered clay which extended to a depth of 9 ft apparently confirming the suggestion (Figure 42). Similarly, the clay pocket encountered at (220,80) may be part of a feature which not only extends back toward the area of main cavity system but toward anomaly B at (225,40).

Comparison of Quantitative Gravity Interpretations and the Known Cavity System

71. Profile lines I, II, III, and V of the tabulation in paragraph 52 and Figure 33 cross anomaly A caused by the main cavity system. Figure 44 shows these profile lines in relation to the cavity system. The quantitative interpretation procedure attempts to find the particular box-shaped model, which is square in plan and has thickness equal to the depth to its top, which produces a gravity effect that best fits the observed residual gravity anomaly data along the profile lines. For a profile line such as V which crosses multiple features for which the gravity effects superimpose to produce a composite anomaly, the quantity that is correctly interpreted is the total mass excess or deficiency, but the interpreted model in such cases may have little relation to the actual multiple features.

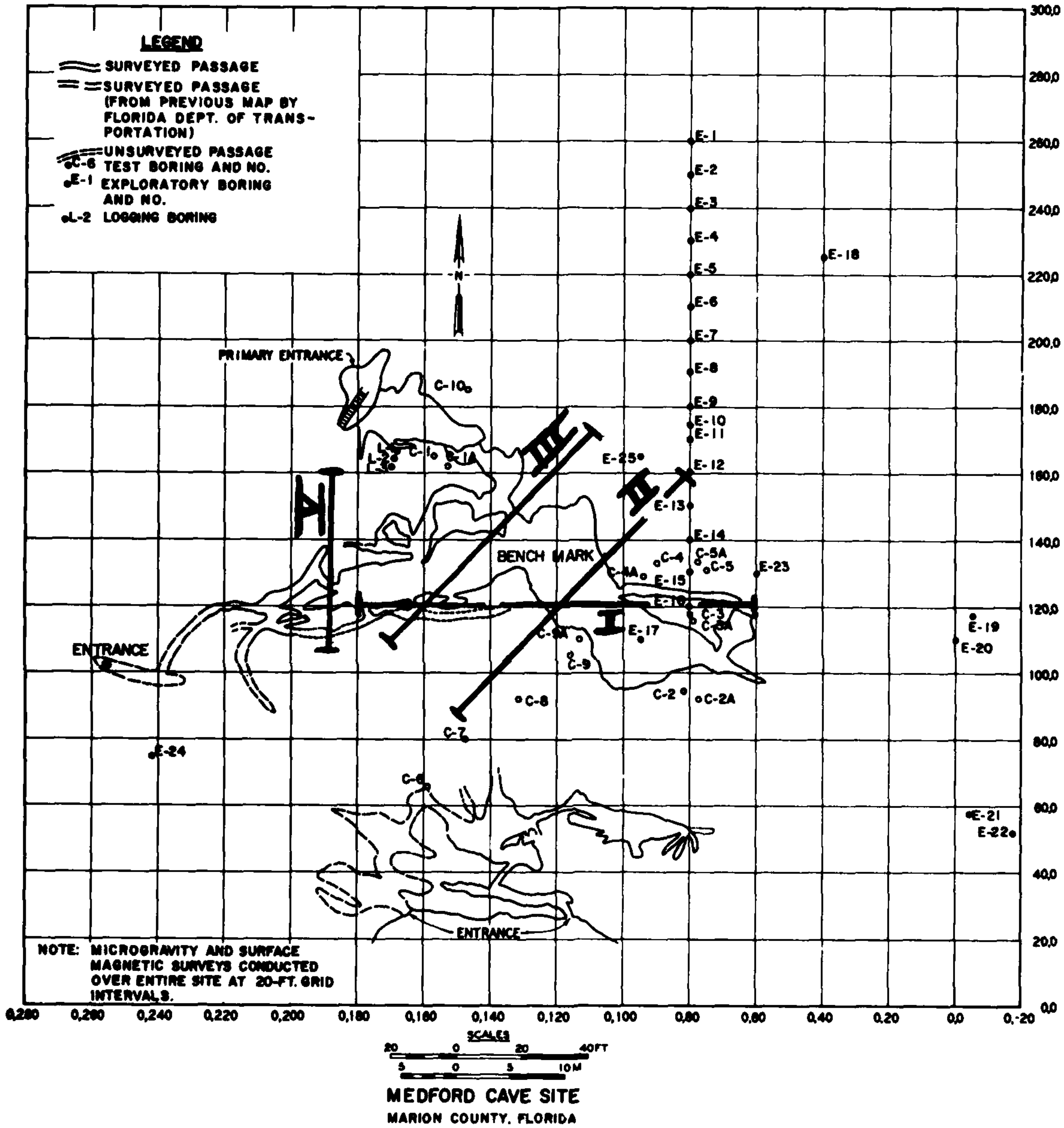


Figure 44. Location of four profiles across main cavity system used for quantitative interpretation

72. The quantitative interpretations are compared with the mapped depths and sizes of the cavity system in the following tabulation:

Profile	Depth to Top, ft		Thickness, ft		Width, ft	
	Gravity Model	Mapped	Gravity Model	Mapped	Gravity Model	Mapped
I	12.2	15	12.2	11	33.6	30
II	15.1	11	15.1	11	30.2	24
III	14.8	14	14.8	9	29.6	30
I&II (Average)	13.7	13	13.7	11	31.9	27

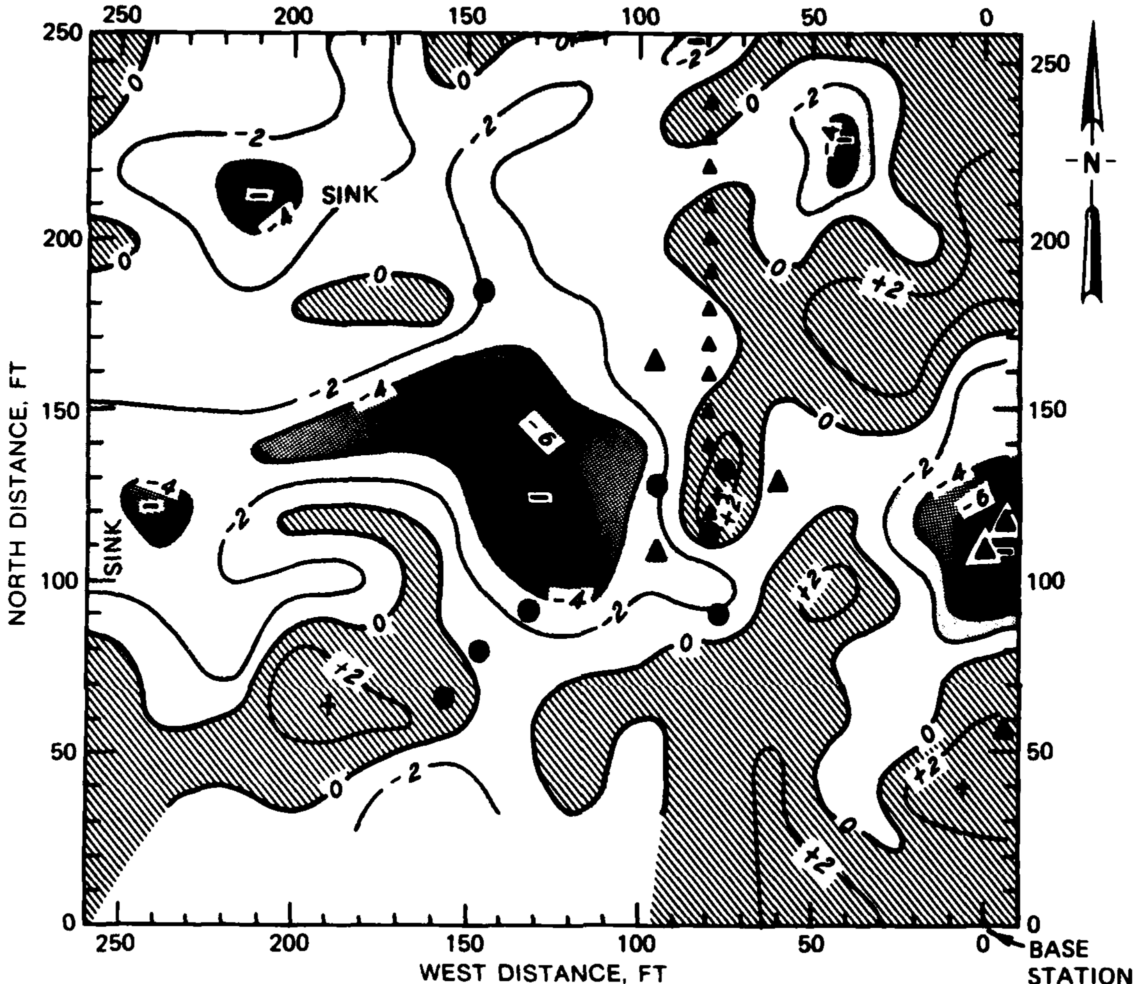
The mapped dimensions are clearly averages or typical values for the features under the profiles. The final listing is an average for profiles I and II across the Big Room. Listed mapped widths are along the profile lines; a square with the same area as the plan area of the cavity system would have sides of length 35 ft, giving somewhat better agreement with the gravity models. The density contrasts for profiles I, II, and III for the gravity models agree very closely and are reasonable (see paragraph 52). Agreement between the gravity models and the "Big Room" area of the cavity system is quite good considering the assumptions and differences between model and actual system. Note that the larger dimensions predicted for the models than the mapped dimensions are consistent with the observation noted earlier that gravity anomalies are generally larger due to secondary effects around cavities.

73. Direct comparison of profile VI across anomaly C with drilling data is complicated by the fact that the profile is apparently not across the center of the anomaly. The depth to top of the solution feature is 12 ft (boring E19) compared to the 16.8 ft for the quantitative interpretation. Thickness is 15 ft compared to 16.8 ft from the quantitative interpretation.

74. Comments at the end of the discussion on the 80 N-S line suggest the use of gravity anomaly contour maps in a qualitative way to zone a site with regard to areas which may have anomalous subsurface conditions. These site zoning maps can then be used to guide and plan drilling and sampling programs. If the drilling results verify the

zoning map predictions, the zone map can then be used qualitatively to predict solution features or to extend the known solution conditions to undrilled areas on the zoning map. Zoning maps can be prepared from various types of geophysical survey results, and in future reports in this series zoning maps for the Medford site based on resistivity, acoustic resonance, seismic methods, etc., will be presented.

75. Figures 45 and 46 are "shades of gray" zone maps prepared from Figures 23 and 24. The cross-hatched pattern indicates positive anomaly areas which presumably are areas without significant solution features. Of the 11 borings in positive anomaly areas of the map, only 3 encountered cavities: C6(66,158), E8(190,80), E21(57.5,-4). Boring C6 encountered a 1.5-ft cavity at a 38-ft depth which represents a case clearly beyond the detectability limits of the microgravimetric method. Boring E8 encountered a 2.0-ft cavity at a 17-ft depth; this represents a depth-to-thickness (diameter) ratio of 8.5, which is just outside the detectability limits of the method (Butler 1980). Note that E8 is close to the boundary of the positive anomaly zone. Referring to the boring log for boring E21 (Appendix B), the vertical thickness of cavities is sufficient that a negative gravity anomaly should have been detected; however, boring E22 (52,-17.5) detected no cavities (to its total depth of 20 ft), and thus it is possible that the cavities at (57.5,-4) may be small in lateral extent. The gravity data values at (40,0) and (50,0) were two of the ten values deleted before contouring; thus the actual gravity field in this area of the 0 N-S profile line was not very well sampled. In any event, a significant vertical thickness of cavities was undetected by the accepted gravity anomaly map at the location of boring E21.

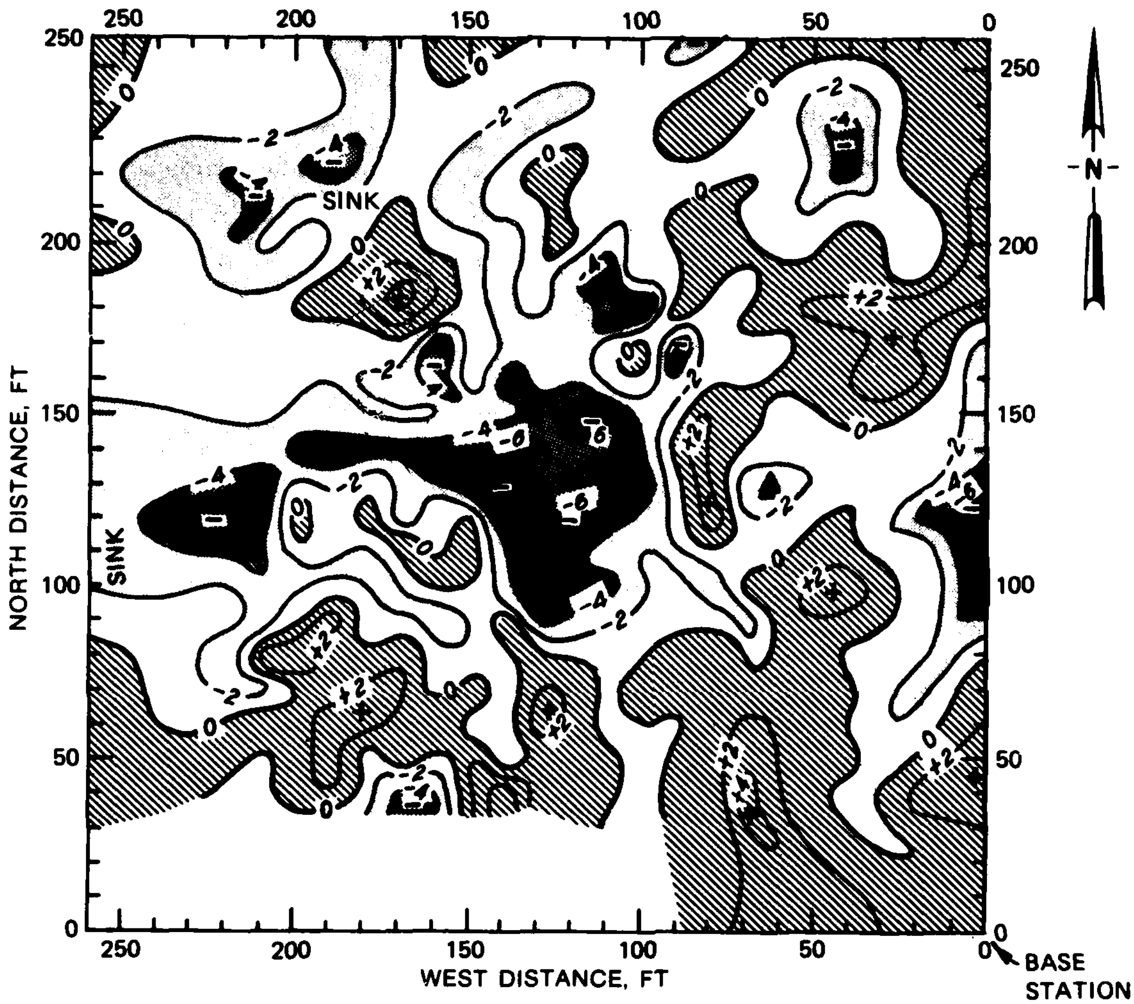


● TEST BORING
▲ EXPLORATORY BORING
▲ CONFIRMATORY BORING
− NEGATIVE GRAVITY ANOMALY REGION
+ POSITIVE GRAVITY ANOMALY REGION

<-60 μGAL
-40 — -6- μGAL
-20 — -40 μGAL
0 — -20 μGAL
>0

NOTE: CONTOUR INTERVAL = 0.02 mGAL (20 μGAL)
STATION SPACING = 20 FT

Figure 45. Medford Cave site zoning map prepared from Residual Gravity Con.our Map (20-ft spacing data)



▲ CONFIRMATORY BORING
− NEGATIVE GRAVITY ANOMALY REGION
+ POSITIVE GRAVITY ANOMALY REGION

<-60 μGAL
-40 — -6- μGAL
-20 — -40 μGAL
0 — -20 μGAL
>0

NOTE: CONTOUR INTERVAL = 0.02 mGAL (20 μGAL)
STATION SPACING = 10 FT

Figure 46. Medford Cave site zoning map prepared from Residual Gravity Contour Map (10-ft spacing data)

PART VI: SUMMARY AND CONCLUSIONS

Summary

76. This report presents the results of surveys using two geophysical methods, microgravimetric and magnetic, at the Medford Cave site, Fla. As part of a larger research program, the objective is to assess the applicability of the methods for the detection and delineation of subsurface cavities. Results of the assessments in this report and others to follow give guidance for planning and conducting site investigations in karst regions (or other areas where subsurface voids are suspected, such as abandoned mines). The motives for including geophysics in a site investigation program are twofold: (a) economics--a combined geological, geophysical, and drilling program can more economically achieve the required site definition than a closely spaced comprehensive drilling program alone, and (b) overall site characterization--geophysics coupled with selective drilling can often reveal geological patterns at the site which can be missed or overlooked in comprehensive drilling programs.

77. The two geophysical methods discussed in detail in this report are passive potential field methods. Their use is indicated for site investigations where anomalous site conditions such as faults, cavities, or other solution features, lateral density changes, etc., are expected or possible. Results of a third geophysical method, electrical resistivity surveying, are presented for correlation with the gravity and magnetic results. Two types of interpretation of the gravity data are presented: qualitative and quantitative. The qualitative interpretation method uses gravity anomaly maps to locate anomalous zones in plan. For surveys in karst areas, if residual anomaly maps are prepared, then all negative anomaly areas are suspect and should be selectively drilled for verification. It should be remembered, however, that localized relative lows may be indicative of small solution features even if located in positive residual anomaly areas. Quantitative interpretation

of selected gravity profiles is illustrated and seen to agree fairly well with known subsurface features.

78. Importantly, this report considers and illustrates the value of complementary geophysical surveys for site investigations. In particular, profiles of gravity, resistivity, and magnetic data are examined and compared to the results of a verification drilling program. Simple, qualitative criteria, such as given in paragraph 61, allow predictions as to the cause of anomalies which can be correlated on two or more data profiles.

Conclusions

79. The magnetic method appears to be of rather limited usefulness for geotechnical investigations including cavity detection in karst areas, although magnetic methods have been used very successfully for locating abandoned mine shafts at shallow depths. The magnetic method may also be of value in the detection of very shallow clay-filled cavities or pockets. Although some correlation was observed at the Medford site between magnetic anomalies and other geophysical anomalies and with geological conditions revealed by drilling, the magnetic survey in general did not yield results which were of value in defining this site. However, since susceptibility measurements were not made on the clays and limestones at the Medford site, a general statement cannot be made regarding applicability at other sites in karst areas where a larger clay-limestone susceptibility contrast might exist. In any event, it is unlikely that a clay-filled cavity or pocket will be detectable in a magnetic survey if its size is not of the same order as its depth of burial or if the depth to the top of the feature exceeds about 10 ft (3 m).

80. Microgravimetric methods are of more general applicability for geotechnical site investigations. At the Medford Cave site, the results of the microgravimetric survey successfully delineated in plan the known cavity system, which varied in depth from about 10 ft (3 m) to about 30 ft (10 m) to the top, and led to the discovery of unknown

solution features and trends. Comparison of a gravity profile line with a detailed geologic cross section revealed excellent correlation with small-scale clay pockets and limestone pinnacles and detected a known cavity which passed beneath the profile line at a depth to center of about 24 ft (7.3 m) and with an effective diameter of 9 ft (2.7 m) for a depth-to-thickness (diameter) ratio of 2.7. Six selected negative anomaly features were specifically drilled for verification purposes, and all borings intercepted air- or clay-filled cavities or clay- or sand-filled pockets in the limestone. Of 11 borings in positive anomaly areas, only 3 intercepted cavities.

81. The cavity system was adequately detected and delineated using a 20-ft (6.1 m) station spacing.* A station spacing of 10 ft (3 m) allowed detection of small-scale cavities and other solution features in the top of the limestone. For a reconnaissance survey of similar sites, a station spacing of 20 ft should be adequate for detecting zones with solution features that might pose threats to bearing capacity, for example. Of course, the adequacy of a gravity anomaly map prepared from data obtained with a given grid spacing depends on the purpose of the site investigation. If detecting small-scale solution features is important, such as the limestone pinnacles and clay pockets at this site, then clearly a grid spacing of 20 ft would be too coarse for definition or delineation.

82. Even though it has been stated that the microgravimetric survey delineated the known cavity system, the significance of this terminology must be emphasized. First of all, the gravity anomaly maps detected the location in plan of the known cavity system. Next, the complex gravity anomaly due to cavity system correctly defined the known directional trends of the system. Qualitatively, the magnitude and areal extent of the complex anomaly give an idea of the sizes and depths of the cavity system. Assumption of a simple geometry allows quantitative estimates of size, depth, and density contrast. Although the

* A station spacing as large as 40 ft would have allowed detection of the main cavity system, although orientation trends would not have been well defined.

gravity anomaly maps, particularly the map for a 10-ft grid over the cavity system, suggest more than a single solution feature for the west-southwest extension of the cavity system, for example, the individual cavities are not individually resolved. Indeed, for the gravity anomaly above two cavities at the same depth to be resolved (i.e., separated into two separate anomalies), the separation of the cavities must be about 1.2 times the depth (Butler 1980). Thus, the occurrence of multiple cavity features close together will result in a gravity anomaly which is the superposition of the individual anomalies and may not indicate the separate features.

83. Using simple model assumptions, computed depths to tops of cavities agree to better than 25 percent, thicknesses to better than 40 percent, and areal extent of cavities to better than 15 percent of known cavity dimensions. These percentages are completely model-dependent and in no way reflect the accuracy of the survey or the microgravimetric technique. In general, since indicated geophysical anomalies must ultimately be drilled at least selectively for verification, the location of anomalous areas in plan is essentially all that is required from the geophysical surveys. Use of gravity data to estimate depths to features causing anomalies, however, can be accomplished without much expenditure of time and can be of value in some cases.

84. Three conditions can limit the applicability of microgravimetric surveys to site investigations in karst areas. The first condition is extreme topographic variation. As can be seen from Figure 17, however, the number of stations significantly affected by the sinks at the Medford site is not large. The manner in which the extreme topographic feature will affect gravity data can often be predicted even though it may be difficult to apply proper terrain corrections. The second condition is the presence of a high level of lithological noise, which is simply defined as gravity fluctuations due to shallow, lateral density variations. Lithological noise can arise due to lateral changes in soil type or, in the case of the Medford site, due to fluctuations in depth to top of rock beneath a thin soil cover. Although the detection of a pinnacled limestone surface such as shown in Figures 5 and 14 is an

important objective, the lithological noise from the pinnacled surface may mask gravity anomalies caused by underlying cavities. Even though the amplitude of the "noise" level on the right side of the profile in Figure 41a is about 20 μGal, this does not necessarily imply that the detectability limit for cavities is limited to anomalies greater than 20 μGal, since the anomalies due to deeper sources will also have longer spatial wavelengths. In any event, the presence of lithological noise will complicate the detection of anomalies due to the small cavity features. The noise at the Medford site did not interfere with the delineation of the known cavity system, although the amplitudes of the anomalies over the main cavity system may be larger or smaller in places due to the noise. The third condition which can limit the applicability of microgravimetric surveys results from the resolution considerations in paragraph 82. If there are multiple cavities or other solution features which are close together, the individual cavities may not be identified. That is, an isolated cavity may be easier to detect than a similar cavity surrounded by many other cavities; in such a case, the gravity anomaly produced by the cavity complex will be detected as a superposed anomaly.

REFERENCES

Arzi, A. A. 1975. "Microgravimetry for Engineering Applications," Geophysical Prospecting, Vol 23, pp 408-425.

Ballard, R. F. 1976. "Method for Crosshole Seismic Testing," Journal, Geotechnical Engineering Division, American Society of Civil Engineers, Vol 102, pp 1261-1273.

Baranov, W. 1975. Potential Fields and Their Transformations in Applied Geophysics, Gebriiden Borntraeger, Berlin.

Bates, E. R. 1973. "Detection of Subsurface Cavities," Miscellaneous Paper S-73-40, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Burton, A. N. and Maton, P. I. 1975. "Geophysical Methods in Site Investigations in Areas of Mining Subsidence," Site Investigations in Areas of Mining Subsidence, Newnes-Butterworth, London.

Butler, D. K., ed. 1977. "Proceedings of the Symposium on Detection of Subsurface Cavities," U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Butler, D. K. 1980. "Microgravimetric Techniques for Geotechnical Applications," Miscellaneous Paper GL-80-13, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Butler, D. K. and Murphy, W. L. 1980. "Evaluation of Geophysical Methods for Cavity Detection at the WES Cavity Test Facility," Technical Report GL-80- , U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Butler, D. K., Skogland, G. R., and Landers, G. B. 1978. "CROSSHOLE--An Interpretive Computer Code for Crosshole Seismic Test Results," Miscellaneous Paper S-78-8, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Butler, D. K., et al. 1982. "Analytical and Data Processing Techniques for Interpretation of Geophysical Survey Data," Miscellaneous Paper GL-82-16, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Cooper, S. S. and Bieganousky, W. A. 1978. "Geophysical Survey of Cavernous Areas, Patoka Dam, Indiana," Miscellaneous Paper S-78-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Curro, J. R., Cooper, S. S., and Ballard, R. F. 1980. "Cavity Detection-Delineation in Karst Areas: An Investigation Using Seismic and Acoustic Methodology," 50th Annual Meeting of the Society of Exploration Geophysicists, Houston, Tex.; Abstract in Geophysics, Vol 46, p 452.

Dearman, W. R., Baynes, F. J., and Pearson, R. 1977. "Geophysical Detection of Disused Mineshafts in the Newcastle upon Tyne Area, North-East England," Quarterly Journal of Engineering Geology, Vol 10, pp 257-269.

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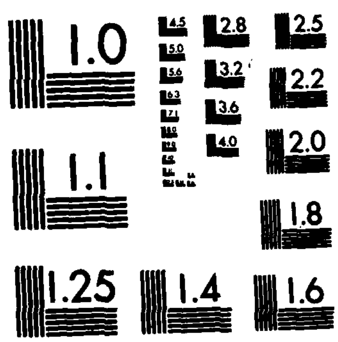

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Elkins, T. A. 1951. "The Second Derivative Method of Gravity Interpretation," Geophysics, Vol 16, pp 29-50.

Faulkner, G. L. 1970. "Geohydrology of the Cross-Florida Barge Canal Area with Special Reference to the Ocala Vicinity," Open File Report, U. S. Geological Survey, Tallahassee, Fla.

Fountain, L. S., Herzig, F. X., and Owen, T. E. 1975. "Detection of Subsurface Cavities by Surface Remote Sensing Techniques," Report No. FHWA-RD-75-80, Federal Highway Administration, Washington, D. C.

Franklin, A. G. 1980. "Interpretation of Data from Uphole Refraction Surveys," Miscellaneous Paper GL-80-5, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hooper, W. and McDowell, P. 1977. "Magnetic Surveying for Buried Mine Shafts and Wells," Ground Engineering, March 1977.

LaFehr T. R. 1979. "Gravity and Magnetic Methods," Geophysical Methods in Geotechnical Engineering, American Society of Civil Engineers Convention, Atlanta, Ga.

Longman, I. M. 1959. "Formulas for Computing the Tidal Acceleration Due to the Moon and Sun," Journal of Geophysical Research, Vol 64, pp 2351-2355.

McDowell, P. W. 1975. "Detection of Clay Filled Sink-holes in the Chalk by Geophysical Methods," Quarterly Journal of Engineering Geology, Vol 8, pp 303-310.

Neumann, R. 1979. "Medford Cave Site--Florida, Microgravity Survey," Letter report to U. S. Army Engineer Waterways Experiment Station, Compagnie Generale de Geophysique, Massy, France.

Telford, W. M., Geldhart, L. P., Sheriff, R. E., and Keys, D. A. 1976. Applied Geophysics, Cambridge University Press, New York, Chapters 2 and 3.

APPENDIX A: GEOLOGY IN THE AREA OF MEDFORD CAVE, MARION COUNTY, FLORIDA

General Surficial Geology

1. The Medford Cave site is located in East Central Section 38 T 13 S, Range 21 E, Marion County, Fla., approximately 1.1 miles south of the Post Office in Reddick, Marion County, Fla., and west of old US 441.

2. The land is partially in woods, and the remainder is used for cattle grazing and crops. The water drainage is interior with no surface streams present. Ponds, sinks, caves, and open limestone quarries aid in water recharge to the underground Floridan aquifer. Rainfall seeps rapidly through the sand and clayey surficial materials and continues downward to the potentiometric surface of the Floridan aquifer. In this area of Marion County, the potentiometric surface stands at about 50 ft above mean sea level. There are very few natural outcroppings of "Ocala" limestone in the area because of the overlying thin, younger formations and yet more recent alluvium. The "Ocala" limestone is apparent in sinks and caves and where surficial residual boulders are present. Man-made outcrops of this limestone occur in roadcuts and limestone quarries.

3. The local relief in the Medford Cave area is about 110 ft. This relief is due to solution of the soft underlying limestone. Typically, the higher hills are capped with quartz sand, clayey sand, and, in some instances, clay. The sand and clayey sand is generally much thinner on the sides of the hills, and much thicker in the low areas at the foot of the hills.

4. Many active and inactive limestone quarries occur in the general area. Commercial grade limestone is present in many counties of Florida. In the Marion County area, however, the high elevation of the top of the limestone results in a greater quantity of limestone available for mining above water level. These higher limestone elevations have made it possible for karst feature development to proceed to greater maturity. Caves, open sinks, clay-filled solution pipes, open-solution pipes, and horizontal-filled and open conduits are typical of these higher limestone areas.

Ocala Uplift

5. The Florida Plateau is composed of a thick series of shallow marine deposits, dominantly limestones, which are underlain by rocks of Paleozoic age. The core of the Florida Plateau is composed of metamorphic and igneous rocks. These crystalline rocks occur at great depth. There is little evidence that the limestones of the Florida Plateau have undergone extensive deformation, though the elongate Ocala Uplift of Post-Oligocene time created positive areas in Florida. The central axis of the Ocala Uplift trends NNW, and the oldest rocks within the uplift area are located in the center of the dome in Levy County, Fla. Here the dome has been truncated by erosion, exposing the Avon Park Formation of Eocene age. Levy County is in northwest coastal peninsular Florida. The formational dips in the vicinity of the Ocala Uplift vary from 2.5 to 12 ft per mile. The limits of the Ocala Uplift exceed 165 miles in length and 60 miles in width.

General Stratigraphy

6. The general stratigraphy of the Medford Cave locality is represented by rocks of Eocene through Recent age. Eocene is the oldest series of rock units exposed in the State of Florida and is the principal age of rocks encountered in the Medford Cave area. The Medford Cave area lies near the east-central flank of the Ocala Uplift. The top of the oldest outcropping formation associated with the Ocala Dome is the Avon Park Limestone of Eocene age (Claiborne stage). The area of the outcrop of the Avon Park Limestone lies approximately 33 miles west-southwest of the Medford Cave locality. Near the Medford Cave locality in Section 2, T 13 S, Range 21 E, the Avon Park Limestone top is reported to occur at a point 89±5 ft below sea level. This detection of the top of the Avon Park Limestone lies about 2.45 miles northeast of the post office in Reddick, Fla., or approximately 3.4 miles northeast from the Medford Cave locality.

7. Overlying the Avon Park Limestone in the Medford Cave locality

are the Inglis, Williston, and Crystal River Formations. These latter three formations are of the Ocala Group of limestones of Jackson stage. The Oligocene series of rock formations are missing in the Medford Cave area, but a portion of the Miocene series is present in the area. The Hawthorne Formation of Miocene age overlies the Crystal River Formation of Eocene age. The unconformity is sharp. Overlying the Miocene Hawthorne Formation (limestone) at the Medford Cave area are Recent clayey sands and sands.

8. Based on microfaunal data, the Eocene limestone tops (Avon Park, Inglis, and Williston Formations) vary appreciably in elevation relative to sea level, even over short distances. This is due not only to a regional dip, but also due to an uneven depositional surface. Reports resulting from drill hole data show the Williston Formation top to stand at 13 to 18 ft above sea level in Section 2, T 13 S, Range 21 E, or 3.42 miles northeast from the Medford Cave locality; and, additional reports show the Williston Formation top to stand at 65 ft above sea level at Kendrick in Marion County, which is 6.86 miles south of the Medford Cave area.

9. Based on the above data, at least 80 ft of limestone of the Crystal River Formation are present at the Medford Cave locality. It is within this stratigraphic unit that Medford Cave is developed. The next underlying stratigraphic unit, the Williston, will be at least 25 ft in thickness. The Inglis Formation is about 75 ft in thickness. Thus, the total thickness of the Ocala limestones in the Medford Cave area is about 180 ft. The three Ocala limestones, Inglis, Williston, and Crystal River, have been delimited to a great degree by microfauna content, and many accurate lithologic and faunal well studies have yet to be completed in order to determine formational tops, bottoms, and thicknesses. Geographically oriented accurate lithologic cross sections do not exist.

10. The Ocala limestones are generally very pale orange in color, though they may appear white. The Inglis Formation is the hardest of the three formations, the Williston is intermediate in hardness, and the Crystal River Formation is the softest of the group. Identification of

the three formations is generally made by microfauna, although the Inglis Formation in some areas contains as much as 44 percent magnesium carbonate, and is light gray to medium yellow-brown in color. Generally, though, the Ocala limestones are nearly pure calcium carbonate (98 percent).

11. Overlying the Ocala group of formations at the Medford Cave locality are outliers of the Hawthorne Formation of Miocene age. The Hawthorne Formation is 3 to 8 ft in thickness and is a hard molluscan limestone. The Hawthorne limestone is plate orange to cream in color and is crossbedded in some outcroppings. The limestone contains a prolific assemblage of fossil snails and clams. This basal, hard, Hawthorne limestone forms a "cap" on the higher hills in the Medford Cave area.

12. Overlying the basal Hawthorne limestone is a Hawthorne clay. This Hawthorne clay is medium blue-green in color, soft to "blocky" in texture, and is composed of the clay mineral attapulgite with a minor amount of the clay mineral montmorillonite. Frequently, the clay is slightly sandy and silty and may contain thin stringers of nearly pure silica sand. The silica sand is generally parallel to the bedding plane of the clay. Overlying the Hawthorne clay is a sandy, clayey Hawthorne bed containing phosphate pebbles. This phosphatic bed is overlain by a Recent clayey sand, which is in turn overlain by a Recent very slightly clayey sand. The complete geological section characteristic of the Hawthorne Formation is found on the higher hills in the Medford Cave area.

Jointing

13. There are few data that indicate faulting has occurred in the Medford Cave area of Marion County. Although, there are few data which would indicate fracturing of the rocks resulting from intense faulting and folding, jointing in the area is apparent. Joints in the central Marion County area have been found to strike N 15 to 25°W, N 80 to 83°W, and N 33 to 35°E. The joints are near vertical and show little or no displacement. The joints occur as closed joints or are open as the

result of solution of the limestone by groundwater movement. In instances where the joints are occupied by moving water, the water has followed the joint patterns of least resistance within the soft limestone and has moved downward and laterally toward the potentiometric surface. Upon the widening of a joint set, the moving water may form a cave such as Medford Cave. In time these water-worn joints may become filled with clays and clayey sands. These clayey sands are water-transported from the overlying Hawthorne and Recent Formations. These features appear in a quarry wall as a "filled" cave.

14. Near-vertical chert (flint) dikes occupy joints. These dikes can be 50 ft or more in vertical extent and as much as 2 ft in diameter. Upon outcropping, these chert dikes may strike as much as 600 ft on level ground. Any one of the three joints may either by closed, chert-filled, or may serve as a water conduit. A preferred joint direction is chosen by the moving water, this being that joint most parallel to the downward gradient of the potentiometric surface.

Limestone Surface Features

15. The limestone surface in the Medford Cave area is locally highly irregular, due to solution of the soft Crystal River limestone and the subsequent development of karst features, such as sinks. In some localities at the Medford Cave site, a protective layer of more dense limestone (Hawthorne) is present and has inhibited the development of sink activity in the underlying limestone. Other masses of dense rock materials which influence sink activity are chert masses. These masses not only occur as chert (flint) dikes, but will occur parallel to the limestone bedding plane. The limestone bedding planes are near horizontal; therefore, the long axis of the chert masses are also horizontal. The chert masses are generally lenticular in shape and may be as great as 10 ft in thickness and 20 ft in length. These chert deposits can be as thin as 1 in. and 5 ft long, all of them parallel to the limestone bedding plane. The chert masses are quite dense and hard and apparently were deposited during the time of limestone deposition, since individual

fossils exist in an undisturbed state with a portion of the fossil in the limestone and the remaining portion within the chert. That portion of the fossil within the limestone will be composed of limestone and that portion of the fossil within the chert will be composed of chert. No break is evident as the fossil passes from the limestone to the chert. Those masses of chert which influence sink activity will be present from the surface of the ground to a point 50 ft below the top of the limestone. Downward-moving water within a solution zone will be diverted by the chert mass. Lateral or horizontally moving water which encounters a chert mass may be directed in its movement by the chert mass. It is evident, from the foregoing, that surface features are influenced by chert masses at depth or by hard surficial limestone.

16. Vertical relief on the Ocala limestone surface may be extreme. Where large sinks have developed, this vertical relief may be as great as 100 ft over a horizontal distance of 400 ft. Most of the sinks in the Medford Cave area of Marion County are filled with the overlying younger clays, clayey sands, and sands. The land surface is therefore smooth and may not reflect the highly irregular underlying limestone contact. Beneath the overlying clays and sands, the filled sinkholes appear in plan view as circular in form and may coalesce. In cross section, these sink features are cone-shaped or funnel-shaped, with the greatest width at the limestone surface. Some cone-shaped features have the greatest width at the bottom and are thus inverted. Other solution features appear as vertical pipes, circular in form, with little change in diameter between the bottom and the top. Several generations of sinks may be present.

17. The interior surfaces of the sinks are undulating and smooth, and downward-percolating mineral-laden water will result in the formation of secondary crystalline material on the limestone surface of the sink. The larger and deeper sinks will penetrate the Floridan aquifer and then turn and communicate with a near horizontal conduit. These conduits generally are aligned in the downslope direction of the piezometric surface of the Floridan aquifer and will attempt to follow a limestone joint which has been developed in that preferred direction.

Where these conduits have become filled with clays and clayey sands beneath the piezometric surface, they have been referred to as "seams."

APPENDIX B: BORING LOGS

Hole No.

DRILLING LOG | DIVISION: EE&GD | INSTALLATION: USAE WES | SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site (CWIS)
2. LOCATION (Coordinates or Station): Marion County, FL
3. DRILLING AGENCY: USAE WES
4. HOLE NO. (As shown on drawing title and file number): (E/260,80) E1
5. NAME OF DRILLER: Harried
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 4.8 ft
8. DEPTH DRILLED INTO ROCK:
9. TOTAL DEPTH OF HOLE: 32.0 ft
10. SIZE AND TYPE OF BIT: NX Core
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES: 1
15. ELEVATION GROUND WATER: None
16. DATE HOLE: STARTED 8/29/79 | COMPLETED 8/29/79
17. ELEVATION TOP OF HOLE: 166.2
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: DR Butler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
166.2	0		SAND, dk gray, loose, fine, Sl clayey silt organic			
	2–4		Grayish tan			
	4.8	4.8	CLAY, lt gray, dry, sl silty, w/ls fragments slt gray-green plastic (montmorillonite)			
	10–16		sandy, sl silty pale blue green, sandy w/flecks of Fuller's earth w/ls fragments			
	18.3	18.3	Ls, soft, white*, powdery, chalky, dry.	≲20		
	20–24		v. fossiliferous, v. porous, clams, corals, forams.	32		
	26–28			40		
	30			~0		
	32	32.0				

* Actually v. pale orange on Munsell Color Chart

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO. (260,80)E1

Hole No.

DRILLING LOG	DIVISION EE&CD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT NX Core
2. LOCATION (Coordinates or Station) Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) (240/80) E3	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER Harried	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER None
	16. DATE HOLE — STARTED 8/29/79 — COMPLETED 8/29/79
7. THICKNESS OF OVERBURDEN 5.3 ft	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE 22.9 ft	19. SIGNATURE OF INSPECTOR D. P. Butler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Augered SAND, br, organics			
	2		Silty SAND, br			
	4					
	5.3	5.3				
	6–14		Ls, soft to hard, white*, fossiliferous, clams, snails, porous, hard to medium hard, with large 1-in. porosity filled with soft ls			
	16–18			0		MASSIVE CORE LOSS
	20–22					
	22.9	22.9				
	24		* Actually very pale orange on Munsell Color Chart			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT) PROJECT HOLE NO. (240,80)E3

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT NX Core
2. LOCATION (Coordinates or Station) Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) E4 (230/80)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER Harried	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE [x] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER None
	16. DATE HOLE — STARTED 8/28/79 — COMPLETED 8/28/79
7. THICKNESS OF OVERBURDEN 4.7 ft	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE 28.4 ft	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Augered Silty SAND, br, organics			
		4.7	Ls, white*, med. hard, porous, fossiliferous Moulded porosity w/fine crystalline calcite in voids (Tampa-Hawthorne), w/dense ls at 8.6-9.0 ft			
			Limestone, white, soft (Ocala), hard zone 8.6 to 9.0 ft Coral, clams			
		28.4				
			* Actually very pale orange on Munsell Color Chart			

Depth scale: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) | PROJECT | HOLE NO. (230,80)E4

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site
2. LOCATION (Coordinates or Station): Marion County, FL
3. DRILLING AGENCY: USAE WES
4. HOLE NO. (As shown on drawing title and file number): (220,80) E5
5. NAME OF DRILLER: Harried
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 9 ft
8. DEPTH DRILLED INTO ROCK:
9. TOTAL DEPTH OF HOLE: 27.9 ft
10. SIZE AND TYPE OF BIT: NX Core
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES: 1
15. ELEVATION GROUND WATER: None
16. DATE HOLE: STARTED 8/28/79 | COMPLETED 8/31/79
17. ELEVATION TOP OF HOLE:
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: DkBettler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Silty SAND, brown, organic			
	2		CLAY, brown, CH			
	6		CLAY, gray, CH, some fossils			
		9	Limestone, white*, soft, fossiliferous coral			
	16		Orange stains @ 17.9 ft			
	22		Chalky, hard limestone nodules, clams			
	28		* Actually very pale orange on Munsell Color Chart			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) | PROJECT | HOLE NO. (220,80)E5

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT NX Core
2. LOCATION (Coordinates or Station) Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) (210,80) E6	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER Harried	14. TOTAL NUMBER CORE BOXES 1
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER None
	16. DATE HOLE STARTED 8/28/79 COMPLETED 8/28/79
7. THICKNESS OF OVERBURDEN 4.2 ft	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE 28.0 ft	19. SIGNATURE OF INSPECTOR DkBettle

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Silty SAND, br			
	2		CLAY, brown, CH, silty			
	4		Limestone, very soft			
	6			0		Small tool drop (0.2') at 7.6 ft
	8		Ls, white, med. hard to hard fossiliferous, clams Orange stained at 8 ft	59		
				31		
	10					
	12		Soft	44		
	14		Orange stained @ 14.6 ft			
	16			25		
	18					
	20			74		
	22					
	24			38		
	26					
	28	28				

* Actually very pale orange on Munsell Color Chart

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) PROJECT HOLE NO. (210,80)E6

Hole No.

DRILLING LOG	DIVISION: EE&CD	INSTALLATION: USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site	10. SIZE AND TYPE OF BIT: NX Core
2. LOCATION (Coordinates or Station): Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY: USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
4. HOLE NO. (As shown on drawing title and file number): E7 (200,80)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER: Harried	14. TOTAL NUMBER CORE BOXES: 1
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: None
	16. DATE HOLE: STARTED 8/28/79; COMPLETED 8/28/79
	17. ELEVATION TOP OF HOLE
7. THICKNESS OF OVERBURDEN: 2.2 ft	18. TOTAL CORE RECOVERY FOR BORING %
8. DEPTH DRILLED INTO ROCK	19. SIGNATURE OF INSPECTOR: D.P. Kittle
9. TOTAL DEPTH OF HOLE: 27.7 ft	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Silty SAND, br, organic	Augered		
	2		CLAY, brown, CH			
	4		Ls, white soft			
	6		Ls, white*, soft, fossiliferous, clams	50		
	8		Orange stained zone @ 8.0 ft	100		Lost circulation @ 9.9 ft
	10–14			94		
	16		CHERT, med. hard, brown, w/Ls porosity	55		
	18–22			15		Massive Core Loss
	24–26			57		
	28	27.7				
			* Actually very pale orange on Munsell Color Chart			

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PROJECT

HOLE NO. (200,80)E7

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS
1. PROJECT Medford Cave Site		10. SIZE AND TYPE OF BIT NX Core	
2. LOCATION (Coordinates or Station) Marion County, FL		11. DATUM FOR ELEVATION SHOWN (TBM or MSL)	
3. DRILLING AGENCY USAE WES		12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500	
4. HOLE NO. (As shown on drawing title and file number) (190,80) E8		13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN	DISTURBED / UNDISTURBED
5. NAME OF DRILLER Harried		14. TOTAL NUMBER CORE BOXES 1	
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ___ DEG. FROM VERT.		15. ELEVATION GROUND WATER None	
		16. DATE HOLE	STARTED 8/28/79 COMPLETED 8/28/79
7. THICKNESS OF OVERBURDEN 4.2 ft		17. ELEVATION TOP OF HOLE	
8. DEPTH DRILLED INTO ROCK		18. TOTAL CORE RECOVERY FOR BORING %	
9. TOTAL DEPTH OF HOLE 26.9 ft		19. SIGNATURE OF INSPECTOR	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Silty SAND, br, organics	Augered		
	2–4		CLAY, br-gr, CH			
	4–6.8	6.8	Ls, white, soft			
	8–12		Ls, poor quality, soft	85		Lost circulation @ 8.2 ft
	12		very soft zone			
	14		Orange stained zone @ 14.2 to 14.8 ft	98		
	16		Clams, oysters			
	18		CHERT, w/Ls-filled pores CAVITY	12		Massive core loss
	20–22	21.9				
	22–26.9	26.9	Ls, some orange stain, fossiliferous	30		

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO. (190,80)E8

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site
2. LOCATION (Coordinates or Station): Marion County, FL
3. DRILLING AGENCY: USAE WES
4. HOLE NO. (As shown on drawing title and file number): E9 (180,80)
5. NAME OF DRILLER: Harried
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 7.8 ft
8. DEPTH DRILLED INTO ROCK:
9. TOTAL DEPTH OF HOLE: 26.5 ft
10. SIZE AND TYPE OF BIT: NX Core
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES: 1
15. ELEVATION GROUND WATER: None
16. DATE HOLE: STARTED 8/27/79 | COMPLETED 8/27/79
17. ELEVATION TOP OF HOLE:
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: DKRitter

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Silty SAND, br, organics	Augered		
	4		CLAY, gr, CH			
	6		CLAY, br-gr, dry, crumbly			
	8		Ls, white w/brown silty CLAY, (weathered Ls)	28		
	12		Ls, white, soft	100		
	16		Soft to very soft Diagonal solution channel from 16.5 to 17.5 ft, very porous, orange stained, approx. 1/2 in. wide Soft, fossiliferous	44		Lost circulation @ 21.5 ft
	22		CAVITY	12		Tool drop, 22-25 ft
	25		Ls, white, soft			
	26					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) | PROJECT | HOLE NO. (180,80)E9

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT NX Core
2. LOCATION (Coordinates or Station) Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) E10 (174.3.80)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER Harried	14. TOTAL NUMBER CORE BOXES 1
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER None
	16. DATE HOLE STARTED 8/27/79 COMPLETED 8/27/79
7. THICKNESS OF OVERBURDEN 12.4 ft	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE 12.6 ft	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0–2		Silty SAND, br, organics	Augered		
	2–12.4		CLAY, gray, CH			
	12.4–		Ls, white soft			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT

HOLE NO. (174.3,80)E

Hole No.

DRILLING LOG	DIVISION EE&CD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site
2. LOCATION (Coordinates or Station): Marion County, FL
3. DRILLING AGENCY: USAE WES
4. HOLE NO. (As shown on drawing title and file number): E11 (170,80)
5. NAME OF DRILLER: Harried
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 6.2 ft
8. DEPTH DRILLED INTO ROCK:
9. TOTAL DEPTH OF HOLE: 26.6 ft
10. SIZE AND TYPE OF BIT: NX Core
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES: 1
15. ELEVATION GROUND WATER: None
16. DATE HOLE: STARTED 8/27/79 COMPLETED 8/27/79
17. ELEVATION TOP OF HOLE:
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: D. Hutler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Silty SAND, br, organic			
	2		CLAY, gr, CH			
	8		Ls, white*, soft to very soft, very fossiliferous, clams, very porous	70		
	14			90		
	18		High angle fracture @ 18 ft	92		
	22		Paste at approx. 21 to 21.5 ft			
	24			30		
	26					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO. (170,80)E11

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site	10. SIZE AND TYPE OF BIT: NX Core
2. LOCATION (Coordinates or Station): Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
3. DRILLING AGENCY: USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
4. HOLE NO. (As shown on drawing title and file number): E12 (160,80)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER: Harried	14. TOTAL NUMBER CORE BOXES: 1
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: None
	16. DATE HOLE: STARTED 8/27/79 COMPLETED 8/27/79
7. THICKNESS OF OVERBURDEN: 3 ft	17. ELEVATION TOP OF HOLE:
8. DEPTH DRILLED INTO ROCK:	18. TOTAL CORE RECOVERY FOR BORING: %
9. TOTAL DEPTH OF HOLE: 22.4 ft	19. SIGNATURE OF INSPECTOR: D. Butler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0–3		Augered Silty sand, dk. brown, organics			
	3–5		Ls., White*, soft, v. porous, fossiliferous clams			
	5–10			80		
	10–14			56		Poor quality core. Pieces badly washed and broken
	14–17.4			~50		
	17.4–22.4		Lost water at 17.4' Chert, large pores filled w/v. soft Ls Lost all core below 19'	32		Lost circulation @ 17.4' Recovery estimated to be 0

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) PROJECT HOLE NO. (160,80)E12

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site
2. LOCATION (Coordinates or Station): Marion County, FL
3. DRILLING AGENCY: USAE WES
4. HOLE NO. (As shown on drawing title and file number): E13 (150,80)
5. NAME OF DRILLER: Harried
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 2 ft
8. DEPTH DRILLED INTO ROCK:
9. TOTAL DEPTH OF HOLE: 14.8 ft
10. SIZE AND TYPE OF BIT: NX Core
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES: 1
15. ELEVATION GROUND WATER: None
16. DATE HOLE: STARTED 8/27/79 | COMPLETED 8/27/79
17. ELEVATION TOP OF HOLE:
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: D.K. Butler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Augered Sand, dk br, silty, organics			
	2		Augered Ls, white, soft			
	4		Ls, white*, soft to very soft, fossiliferous			
	6–8			96		
	10		Calcite, porous in near vertical fracture @ 5.3 to 6.1 ft			
	12–14		v. fossiliferous, v. porous	90		
	16					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO. (150,80)E13

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT NX Core
2. LOCATION (Coordinates or Station) Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) E14 (140,80)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER Harried	14. TOTAL NUMBER CORE BOXES 1
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER None
	16. DATE HOLE STARTED 8/27/79 COMPLETED 8/27/79
7. THICKNESS OF OVERBURDEN 1.2 ft	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE 14.6 ft	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Augered Sand, dk br, organics			
	2		Augered Ls, white, soft			
	4–8		Ls, white*, soft orange br crystals on parting @ 5.3 ft very fossiliferous	74		
	10–14			100		Lost circulation @ 15.2 ft
	16					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT

HOLE NO. (140,80)E14

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS
1. PROJECT Medford Cave Site		10. SIZE AND TYPE OF BIT NX Core	
2. LOCATION (Coordinates or Station) Marion County, FL		11. DATUM FOR ELEVATION SHOWN (TBM or MSL)	
3. DRILLING AGENCY USAE WES		12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500	
4. HOLE NO. (As shown on drawing title and file number) E15 (130,80)		13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN	DISTURBED / UNDISTURBED
5. NAME OF DRILLER Harried		14. TOTAL NUMBER CORE BOXES 1	
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.		15. ELEVATION GROUND WATER None	
		16. DATE HOLE	STARTED 8/27/79 COMPLETED 8/27/79
7. THICKNESS OF OVERBURDEN 2 ft		17. ELEVATION TOP OF HOLE	
8. DEPTH DRILLED INTO ROCK		18. TOTAL CORE RECOVERY FOR BORING %	
9. TOTAL DEPTH OF HOLE 15.2 ft		19. SIGNATURE OF INSPECTOR D K Butler	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Augered Sand, dk br, organics			
	2		Augered Ls, white soft			
	4		Ls, white*, soft to very soft	100		
	6, 8, 10, 12, 14, 16					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT

HOLE NO. (130,80)E1

Hole No.

DRILLING LOG	DIVISION EE&CD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site	10. SIZE AND TYPE OF BIT: NX Core
2. LOCATION (Coordinates or Station): Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY: USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
4. HOLE NO. (As shown on drawing title and file number): (120,80) E16	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER: Harried	14. TOTAL NUMBER CORE BOXES: 1
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: None
7. THICKNESS OF OVERBURDEN: 2 ft	16. DATE HOLE: STARTED 8/27/79; COMPLETED 8/27/79
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE
9. TOTAL DEPTH OF HOLE: 15.3 ft	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR: D R Butler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Augered Sand, dr br, organics			
	2		Augered Ls, white, soft			
	4		Ls, white*, soft to med. hard, broken up	45		
	6		soft	93		
	8–12		soft, horiz. bedding plane at 8.4 ft, porous, very fossiliferous	100		
	12			72		Lost circulation @ 13.8 ft
	14		Chert, dk brown, v. hard, large voids filled w/Ls			
	16					

*v. pale orange

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT

HOLE NO. (120,80) E16

Hole No.

DRILLING LOG

DIVISION: EE&GD	INSTALLATION: USAE WES	SHEET 1 OF 1 SHEETS	
1. PROJECT: Medford Cave Site	10. SIZE AND TYPE OF BIT: NX Core		
2. LOCATION (Coordinates or Station): Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)		
3. DRILLING AGENCY: USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500		
4. HOLE NO. (As shown on drawing title and file number): E17 (110,95)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN	DISTURBED	UNDISTURBED
5. NAME OF DRILLER: Harried	14. TOTAL NUMBER CORE BOXES: 1		
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: None		
	16. DATE HOLE	STARTED 9/5/79	COMPLETED 9/5/79
7. THICKNESS OF OVERBURDEN: 4 ft	17. ELEVATION TOP OF HOLE		
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %		
9. TOTAL DEPTH OF HOLE: 35.3 ft	19. SIGNATURE OF INSPECTOR: D K Butler		

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0–2.5		Clayey sand, brown			
	2.5–4		V. clayey sand, red-br			
	4–9		Ls, white, med. hard, fossiliferous, clams, snails	72		
	9–14		oyster shells	76		
	14–17.5		Chert, br, hard, w/macro. porosity (2-in.) filled w/white Ls	56		
	17.5–20.5		CAVITY	0		
	20.5–25.5		Ls, white, soft, macro-micro fossils	66		
	25.5–28.5			37		
	28.5–30.5		CAVITY	0		
	30.5–35.3		Ls, white, soft	38		

Depth scale: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT

HOLE NO. (110,95)E17

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site
2. LOCATION (Coordinates or Station): 1 mile S. Reddick, FL
3. DRILLING AGENCY: USAE WES
4. HOLE NO. (As shown on drawing title and file number): E18 (225,40)
5. NAME OF DRILLER: Harried
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 6.4 ft
8. DEPTH DRILLED INTO ROCK:
9. TOTAL DEPTH OF HOLE: 32.8 ft
10. SIZE AND TYPE OF BIT: NX Core
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES: 1
15. ELEVATION GROUND WATER: None
16. DATE HOLE: STARTED 9/2/79 | COMPLETED 9/2/79
17. ELEVATION TOP OF HOLE:
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: D K Butler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Sand, dk br, w/clay Silt, rock frags, organics			
	2		Sand, lt br, w/clay, Silt, rock frags			
	6.4		Ls, white, soft, porous	40		Lost circulation @ 8.6'
	9		CAVITY ?			Circulation back @ 10.0'
	10.5		Clay, br, w/rock frags Ls frags, chert frags, w/yellow-br stains			
	14.4		Ls, soft, white, v. fossiliferous, porous	90		
	17		v. soft, large shells Ls paste	79		
	22		Chert, br, hard, w/Ls filled porosity, some voids, w/crystals water staining	36		
				26		
	27		Ls, soft, v. fossilferous, v. porous, large shells	33		
	32.8					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) | PROJECT | HOLE NO. (225,40)E18

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT NX Core
2. LOCATION (Coordinates or Station) Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) E19 (117.5,-5)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER Harried	14. TOTAL NUMBER CORE BOXES 1
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER None
	16. DATE HOLE STARTED 8/31/79 COMPLETED 8/31/79
7. THICKNESS OF OVERBURDEN 2 ft	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE 33.5 ft	19. SIGNATURE OF INSPECTOR DKButler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0–2		Sand, v. clayey, gr. br, w/white phosphatic grains	Augered		
	2–4		Ls, white soft	Augered		
	4–9			100		
	9–11			100		
	11–14		Massive core loss, no tool drops, but no core recovery V. soft zone or void	0		
	14–17			0		
	17–22		Clay, yellow-gray, (montmorillonite), small amount recovered	8		
	22–27		Void or filled w/v. soft material	0		
	27–33.5		Ls, white, soft, chalky zone 31.5 to 33.5 ft	56		

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT

HOLE NO. (117.5,-5)

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS
1. PROJECT Medford Cave Site		10. SIZE AND TYPE OF BIT NX Core	
2. LOCATION (Coordinates or Station) Marion County, FL		11. DATUM FOR ELEVATION SHOWN (TBM or MSL)	
3. DRILLING AGENCY USAE WES		12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500	
4. HOLE NO. (As shown on drawing title and file number) E20 (110,0)		13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN	DISTURBED / UNDISTURBED
5. NAME OF DRILLER Harried		14. TOTAL NUMBER CORE BOXES 1	
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.		15. ELEVATION GROUND WATER None	
		16. DATE HOLE	STARTED 8/31/79 / COMPLETED 8/31/79
7. THICKNESS OF OVERBURDEN 1.7 ft		17. ELEVATION TOP OF HOLE	
8. DEPTH DRILLED INTO ROCK		18. TOTAL CORE RECOVERY FOR BORING %	
9. TOTAL DEPTH OF HOLE 19.3 ft		19. SIGNATURE OF INSPECTOR D R Bittler	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Sand, clayey, dk br to yellow br, Ls frags			
	2		Ls, white, soft to med. hard, v. porous, v. fossiliferous			
	8		Chert, br, hard			
			CAVITY			
	10		Chert, br, hard, w/large open and Ls-filled porosity slight tool drops Orange stains @ 11.0 ft	43		
	18		CAVITY			
			BOH			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) | PROJECT | HOLE NO. (110,0) E20

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site	10. SIZE AND TYPE OF BIT: NX Core
2. LOCATION (Coordinates or Station): Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY: USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
4. HOLE NO. (As shown on drawing title and file number): E21 (57.5,-4)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER: Harried	14. TOTAL NUMBER CORE BOXES: 1
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: None
	16. DATE HOLE: STARTED 9/3/79; COMPLETED 9/4/79
7. THICKNESS OF OVERBURDEN: 2.2 ft	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE: 39 ft	19. SIGNATURE OF INSPECTOR: D. K. Butler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		Clayey sand, dk br	Auger		
	2		Clay, sl. sandy, gr-br, stiff			
			Ls, white, med. hard			
	4–10		corals, clams, hard nodules	48		
	12		CAVITY	0		
	14		Ls, white, soft, clams, snails	19		
	16		CAVITY	7		
	18		Ls			
	20		CAVITY			
	20–22		Ls			
	24		CAVITY w/gr-br clay	~0		
	26		Ls, v. soft; stringers of med. hard Ls, w/gr-br clay in voids	~0		
	34			50		
	36		Seam with br. clay 35.5 to 36.0 ft	84		
	38–40					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO. (57.5,-4) E.

Hole No. 52 - 17.5

DRILLING LOG	DIVISION: Geotechnical Lab	INSTALLATION: WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site	10. SIZE AND TYPE OF BIT: 3" core
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY: Mobile District Corps of Engineers	12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
4. HOLE NO. (As shown on drawing title and file number): 52, - 17.5	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED — UNDISTURBED —
5. NAME OF DRILLER: Herbert Owens	14. TOTAL NUMBER CORE BOXES: 1
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: none
	16. DATE HOLE: STARTED 11 June 80; COMPLETED 11 June 80
	17. ELEVATION TOP OF HOLE
7. THICKNESS OF OVERBURDEN: 2.5 ft	18. TOTAL CORE RECOVERY FOR BORING: 12 %
8. DEPTH DRILLED INTO ROCK: 17.5 ft	19. SIGNATURE OF INSPECTOR: Charlie White
9. TOTAL DEPTH OF HOLE: 20.0 ft	

ELEVATION a	DEPTH ft b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		sand, silty, black, grading into grey clay with ls nodules	no sample		flight auger to 5.2 ft; to of limestone at 2.5 ft; is very soft could have probably augered to 20 ft
			Ls, white, very soft, fossiliferous, scattered chert fragments	Run 1 33%	Box 1	
	10			Run 2 5%		
	20					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT: Medford Cave Site HOLE NO. 52 - 17.5

Hole No. 130, 60

DRILLING LOG	DIVISION Geotechnical Lab	INSTALLATION WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Medford Cave Site
2. LOCATION (Coordinates or Station):
3. DRILLING AGENCY: Mobile District Corps of Engineers
4. HOLE NO. (As shown on drawing title and file number): 130, 60
5. NAME OF DRILLER: Herbert Owens
6. DIRECTION OF HOLE: [x] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 3.0 ft
8. DEPTH DRILLED INTO ROCK: 23.6 ft
9. TOTAL DEPTH OF HOLE: 26.6 ft
10. SIZE AND TYPE OF BIT: 3" core
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED -- UNDISTURBED --
14. TOTAL NUMBER CORE BOXES: 1
15. ELEVATION GROUND WATER: none
16. DATE HOLE: STARTED 9 June 80 COMPLETED 10 June 80
17. ELEVATION TOP OF HOLE:
18. TOTAL CORE RECOVERY FOR BORING: 38 %
19. SIGNATURE OF INSPECTOR: [signature]

ELEVATION a	DEPTH ft b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		sand, silty black, grading into grey clay with ls nodules	no sample		flight auger to 4.2 ft, top of rock at 3.0 ft
			Ls, white to pink, hard, fossiliferous, scattered chert	Run 1 100%	Box 1	
	10		Ls, soft below 8.2 ft; very soft zone from 13.5 ft to 17.0 ft with tan water return	Run 2 7%		
				Run 3 5%		lost most of water return at 130 ft
	20			Run 4 41%		
	30					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT: Medford Cave Site HOLE NO. 130, 60

Hole No. 68. 245

DRILLING LOG	DIVISION Geotechnical Lab	INSTALLATION WES	SHEET 1 OF 1 SHEETS

1. PROJECT: Walford Cave Site	10. SIZE AND TYPE OF BIT: 3" core
2. LOCATION (Coordinates or Station):	11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
3. DRILLING AGENCY: Mobile District Corps of Engineers	12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
4. HOLE NO. (As shown on drawing title and file number): 68. 245	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED — ; UNDISTURBED —
5. NAME OF DRILLER: Herbert Owens	14. TOTAL NUMBER CORE BOXES: 1
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: none
	16. DATE HOLE: STARTED 11 June 80; COMPLETED 11 June 80
	17. ELEVATION TOP OF HOLE: —
7. THICKNESS OF OVERBURDEN: 3.5 ft	18. TOTAL CORE RECOVERY FOR BORING: 8 %
8. DEPTH DRILLED INTO ROCK: 22.5 ft	19. SIGNATURE OF INSPECTOR: Charles Waller
9. TOTAL DEPTH OF HOLE: 26.0 ft	

ELEVATION a	DEPTH ft. b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		sand, black grading into black clay with ls nodules	no sample		flight auger to 3.5 ft
			Ls, white, soft, fossiliferous; most of core sample was hard fossil casts and molds; soft is washed away	Run 1 21%		lost water return at 6 ft, no cavities
	10			Run 2 5%	Box 1	RQD = 0
	20			Run 3 4%		
	30					jammed core barrel into soft ls the last 0.2 ft; ls was very soft and granular

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT)

PROJECT: Walford Cave Site HOLE NO. 68. 245

Hole No. 165, 95

DRILLING LOG	DIVISION Geotechnical Lab	INSTALLATION WES	SHEET 1 OF 1 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT 3" core barrel
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY Mobile District Corps of Engineers	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) 165, 95	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED -- — UNDISTURBED --
5. NAME OF DRILLER Herbert Owens	14. TOTAL NUMBER CORE BOXES 1
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER none
	16. DATE HOLE — STARTED 10 June 80 — COMPLETED 10 June 80
	17. ELEVATION TOP OF HOLE
7. THICKNESS OF OVERBURDEN 9.0 ft	18. TOTAL CORE RECOVERY FOR BORING 10 %
8. DEPTH DRILLED INTO ROCK 16.0 ft	19. SIGNATURE OF INSPECTOR Charles W. Watts
9. TOTAL DEPTH OF HOLE 25.0 ft	

ELEVATION a	DEPTH ft b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		sand, silty, blackish - brown grading into grayish-brown clay at 3 ft.	no sample		used flight auger to 9.0 ft
	10		-- Ls, white, fossiliferous, soft, scattered fragments of chert	Run 1 6%	Box 1	water return changed from white to tannish-pink color at 14.0'
	20			Run 2 20%		---- lost water return at 24.0 ft but no cavity
			Bottom of hole at 25.0 ft			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT Medford Cave Site — HOLE NO. 165, 95

Hole No. L - core

DRILLING LOG

DIVISION	Geotechnical Lab
INSTALLATION	WES
SHEET	1 OF 1 SHEETS
1. PROJECT	Medford Cave Site
2. LOCATION (Coordinates or Station)	
3. DRILLING AGENCY	Mobile District Corps of Engineers
4. HOLE NO. (As shown on drawing title and file number)	L - core
5. NAME OF DRILLER	Herbert Owens
6. DIRECTION OF HOLE	[X] VERTICAL [ ] INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN	3.1 ft
8. DEPTH DRILLED INTO ROCK	97.7 ft
9. TOTAL DEPTH OF HOLE	100.8 ft
10. SIZE AND TYPE OF BIT	3" core
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)	
12. MANUFACTURER'S DESIGNATION OF DRILL	Failing 1500
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN	DISTURBED: -- ; UNDISTURBED: --
14. TOTAL NUMBER CORE BOXES	3
15. ELEVATION GROUND WATER	None
16. DATE HOLE	STARTED: 11 June 80 ; COMPLETED: 13 June 80
17. ELEVATION TOP OF HOLE	--
18. TOTAL CORE RECOVERY FOR BORING	23 %
19. SIGNATURE OF INSPECTOR	[signature]

ELEVATION a	DEPTH ft b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0		sand, fine, black grading to clay with ls nodules	no sample		flight auger to 3.1 ft
			Ls, white to creamy, soft, weakly cemented, friable, fossiliferous (pelecypods, gastropods and macro-forams), scattered fragments of chert	Run 1 28%		
	10	cavity		Run 2 28%		Lost all water return at 8.0 ft
	20			Run 3 20%		Used various drill speeds, drill pressure, and amounts of water; but could not get good core recovery
	30			Run 4 4%		
	40			Run 5 7%		
	50		soft pasty ls, 0.3 ft of core	Run 6 19%		
	60			Run 7 46%		
	70			Run 8 18%		
	80			Run 9 14%		
	90	cavity		Run 10 47%		
	100		[illegible] 100.8			

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT: Medford Cave Site HOLE NO.: L - core

Hole No.

DRILLING LOG | DIVISION: EE&GD | INSTALLATION: USAE WES | SHEET 1 OF 2 SHEETS

1. PROJECT: Medford Cave Site
2. LOCATION (Coordinates or Station): Marion County, FL
3. DRILLING AGENCY: USAE WES
4. HOLE NO. (As shown on drawing title and file number): C1 (162,153)
5. NAME OF DRILLER: Stewart
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE: 60.2 ft
10. SIZE AND TYPE OF BIT: NX Core
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES: 3
15. ELEVATION GROUND WATER: None
16. DATE HOLE: STARTED | COMPLETED
17. ELEVATION TOP OF HOLE: 159.5 ft
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: D. K. Butler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
159.5	0		Sand, br, organics			
	5		Ls, lt gray, hard, w/large fossils, v. porous, dense matrix (Tampa-Hawthorne)			
	11		Clay, dk br, silty, organic	100		
	12		Ls, gray, hard			
	12.5		Ls, white, soft (Ocala-Crystal River)			
	15		1/2 in. chert @ 15 ft			
			Chert 15-17 ft w/large Ls-filled porosity	46		
			, chalky	28		
	25		Chert, br, hard, w/large Ls-filled porosity	24		
	30		Ls, white, med. hard	30		
			soft	18		

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) | PROJECT | HOLE NO. (162,153)

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 2 OF 2 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT NX Core
2. LOCATION (Coordinates or Station) Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) C1 (162,153)	13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER Stewart	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE XX VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE 60.2	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	42					
	44					
	46		Intermittent gray flecks, organic	18		
	48					
	50					
	52					
	54					
	56					
	58		Orange stained porous zone @ 58.2			
	60					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) PROJECT HOLE NO. (162,153) C1

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 2 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT NX Core
2. LOCATION (Coordinates or Station) Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) C2 (92,77.5)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER Stewart	14. TOTAL NUMBER CORE BOXES 3
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER None
	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE 156.7 ft
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE 60.2 ft	19. SIGNATURE OF INSPECTOR D K Butler

ELEVATION a	DEPTH ft b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
156.7	0–2.5		Sand, silty, dk br, organics			
	2.5–8		Ls, white, soft to med. hard	80		
	8–9.5		Chert, br, hard, w/large (2") Ls-filled porosity			Lost circulation @ 8.5'
	9.5–		Ls, white, soft 2" chert seam at 10.0 ft	90		
			orange stained porous zone @ 17.0 ft	60		
			large fossils, clams	100		
			v. large fossils	94		
			pasty zone 28 to 30.2 ft			
			orange stained porous zone @ 32.2 ft	86		
			v. soft	60		
			chalky			

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PROJECT

HOLE NO. (92, 77.5) C2

Hole No.

DRILLING LOG	DIVISION EE&CD	INSTALLATION USAE WES	SHEET 2 OF 2 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number) C2 (92,77.5)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	42			100		
	44					
	46					
	48		Orange stained zone @ 49.2 ft	70		
	50					
	52		med. hard zone @ 51.2 ft			
	54			100		
	56					
	58					
	60					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT

HOLE NO. (92,77.5)C2

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 2 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT NX Core
2. LOCATION (Coordinates or Station) Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) C3 (115.5,80)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED: — UNDISTURBED:
5. NAME OF DRILLER Stewart	14. TOTAL NUMBER CORE BOXES 3
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER None
7. THICKNESS OF OVERBURDEN	16. DATE HOLE — STARTED 8/9/79 — COMPLETED 8/9/79
8. DEPTH DRILLED INTO ROCK	17. ELEVATION TOP OF HOLE 157.2 ft
9. TOTAL DEPTH OF HOLE 61.7 ft	18. TOTAL CORE RECOVERY FOR BORING %
	19. SIGNATURE OF INSPECTOR D K Butler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
157.2	0		Sand, dk br, organics			
	3–4		Ls, white, soft to med. hard			
			Alternating soft & med. hard zones			
	5–10			80		
	10–15		soft	10		
	15–21.5		Chert, @ 16.7 ft			
			v. soft	~0		No tool drops on C3
	21.5–26.5		v. soft	~0		
	26.5–31.5		soft	20		
	31.5–36.5			20		
	36.5–			20		

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) PROJECT HOLE NO. (115.5,80)C

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 2 OF 2 SHEETS

1. PROJECT Medford Cave Site
2. LOCATION (Coordinates or Station)
3. DRILLING AGENCY
4. HOLE NO. (As shown on drawing title and file number) C3 (115.5,80)
5. NAME OF DRILLER
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN | DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE | STARTED | COMPLETED
17. ELEVATION TOP OF HOLE
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	42		v. soft, pasty clay seam @ 44 ft			
	44			90		
	46					
	48			20		
	50					
	52					
	54		orange staining	40		
	56					
	58			20		
	60		orange staining			
	62					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) | PROJECT | HOLE NO. (115.5,80)C3

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 1 OF 2 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT NX Core
2. LOCATION (Coordinates or Station) Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL Failing 1500
4. HOLE NO. (As shown on drawing title and file number) C5 (133.6,77.5)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER Stewart	14. TOTAL NUMBER CORE BOXES 3
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER None
	16. DATE HOLE STARTED 8/10/79 COMPLETED 8/10/79
7. THICKNESS OF OVERBURDEN 2.2 ft	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR D. L. Butler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0–2.2		Sand, dk br, organics			
	2.2		Ls, white, soft			
	5–10			90		
	10–15			90		Lost circulation @ 14 ft
	15–20		v. soft	80		Regained circulation
	20–25		large fossils, open burrow tube	100		Lost circulation @ 21.5'
	25–30		soft v. soft, large fossils	60		
	30.5–32.5		CAVITY clay			
	32.5		Orange stained La Ls, white, soft			
	35–40			70		

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PROJECT

HOLE NO. (133.6,77.5) C5

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 2 OF 2 SHEETS

1. PROJECT Medford Cave Site
2. LOCATION (Coordinates or Station)
3. DRILLING AGENCY
4. HOLE NO. (As shown on drawing title and file number) C5 (133.6,77.5)
5. NAME OF DRILLER
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN | DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE | STARTED | COMPLETED
17. ELEVATION TOP OF HOLE
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	42			90		
	44					
	46–48		v. soft	50		
	50–54		v. porous, some orange staining	90		
	56					
	58		CAVITY	60		
	60		Ls, white, soft, w/orange staining			
	62					

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PROJECT

HOLE NO. (133.6,77.5)C5

Hole No.

DRILLING LOG	DIVISION: EE&GD	INSTALLATION: USAE WES	SHEET 1 OF 2 SHEETS

1. PROJECT: Medford Cave Site	10. SIZE AND TYPE OF BIT: NX Core
2. LOCATION (Coordinates or Station): Marion County, FL	11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
3. DRILLING AGENCY: USAE WES	12. MANUFACTURER'S DESIGNATION OF DRILL: Failing 1500
4. HOLE NO. (As shown on drawing title and file number): C9 (110,113.3)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER: Stewart	14. TOTAL NUMBER CORE BOXES: 3
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: None
	16. DATE HOLE: STARTED 8/10/79; COMPLETED 8/10/79
7. THICKNESS OF OVERBURDEN: 4.4 ft	17. ELEVATION TOP OF HOLE:
8. DEPTH DRILLED INTO ROCK:	18. TOTAL CORE RECOVERY FOR BORING: %
9. TOTAL DEPTH OF HOLE: 60.0 ft	19. SIGNATURE OF INSPECTOR: D K Butler

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	0–4.9		Sand, dk br, organics			
	4.9–10		Ls, white, med. hard calcite crystals on fracture @ 6.0 ft	100		
	10–15		soft	90		
	15–20		Chert, br, hard w/large Ls-filled porosity	20		
	20–25			15		
	25–28.8		Ls, white, soft; v. soft	50		
	28.8–31.5		CAVITY			
	31.5–35		Ls, br, v. soft w/clay; white, soft	40		
	35–40		Sand, lt. br, w/shell-frags; Ls, white, soft	20		

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PROJECT | HOLE NO. (110,113.3)

Hole No.

DRILLING LOG	DIVISION EE&GD	INSTALLATION USAE WES	SHEET 2 OF 2 SHEETS

1. PROJECT Medford Cave Site	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station)	11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
3. DRILLING AGENCY	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number) C9 (110,113.3)	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED — UNDISTURBED
5. NAME OF DRILLER	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE — STARTED — COMPLETED
7. THICKNESS OF OVERBURDEN	17. ELEVATION TOP OF HOLE
8. DEPTH DRILLED INTO ROCK	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
			Ls, white, soft to hard v. fossiliferous			
	42			50		
	44		Ls paste			
	46		brownish zone			
	48			20		
	50		yellow stains			
	52			70		
	54					
	56					
	58			100		
	60					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT

HOLE NO. (110,113.3)C9

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Butler, Dwain K.
Cavity detection and delineation research : Report 1 : Microgravimetric and magnetic surveys : Medford Cave Site, Florida / by Dwain K. Butler (Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, 1983.
136 p. in various pagings : ill. ; 27 cm. -- (Technical report ; GL-83-1, Report 1)
Cover title.
"March 1983."
"Prepared for Office, Chief of Engineers, U.S. Army under CWIS Work Unit No. 31150."
Bibliography: p. 91-92.

1. Caves (Florida). 2. Geophysical research. 3. Gravimeter (Geophysical instrument). 4. Medford Cave (Fla.) I. United States. Army. Corps of Engineers.

Butler, Dwain K.
Cavity detection and delineation research : ... 1983.
(Card 2)

Office of the Chief of Engineers. II. U.S. Army Engineer Waterways Experiment Station. Geotechnical Laboratory. III. Title IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; GL-83-1, Report 1.
TA7.W34 no.GL-83-1 Report 1

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